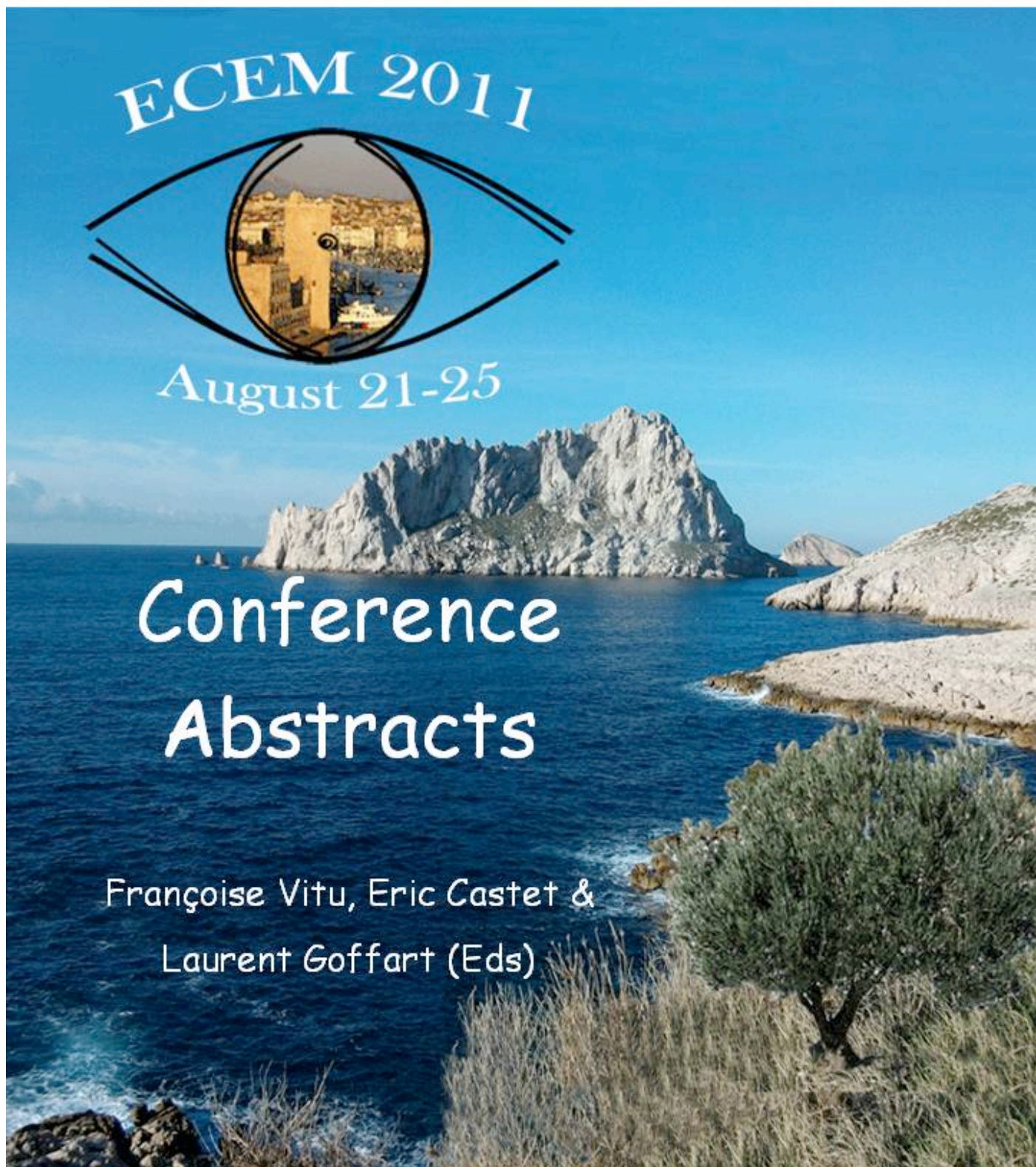


16th European Conference on Eye Movements



ECEM 2011



August 21-25

Conference Abstracts

Françoise Vitu, Eric Castet &
Laurent Goffart (Eds)



Université de Provence Marseille,
France



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16th European Conference on Eye Movements

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Acknowledgments

We would like to warmly thank Stéphanie Desous for the enormous work she did in putting together all the selected abstracts and the scientific program of the conference. We are also indebted to her for making the conference possible and for making it an exceptional event with her insightful ideas and her remarkable and unique efficiency. We also greatly thank Frédéric Lombardo who intervened at many levels in tandem with Stéphanie. Stéphane Dufau took care of all the technical aspects of the conference, including the abstract submission part, and we thank him for all his efforts. We are also indebted to Maria Ktori who conceived the program booklet and contributed in coordination with Françoise Kern, Andrew Meso, Rachel Ostrand and Kim Uittenhove to the edition and the proofreading process of abstracts, as well as Myriam Chanceaux who updated the conference website and program all year long. At a larger scale we thank all members of the organizing team who also greatly contributed to the success of the conference.

We are very grateful to the members of the scientific advisory board of the conference for their reviews of the abstracts, and we particularly thank those who accepted the additional and heavy task of evaluating the posters during the conference.

SR Research was the main partner of ECEM 2011 and we are indebted to them. We also greatly thank all other sponsors for their support: Applied Science Laboratory, Arrington Research, Cognitive Science Society, Cambridge Research Systems, Essilor, the European Union, KyberVision, Interactive Minds, SensoMotoric Instruments, S. Oliver Associates, and at the National level, the "CNRS", the "Conseil Général des Bouches du Rhône", the "GDR Vision", the "IFR Sciences du Cerveau et de la Cognition", the "Pôle 3C", the "Région PACA", the "Université de Provence" and the "Ville de Marseille".

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ECEM, a 30-year old Conference

In the early 1980s, under the initiative of Rudolf Groner (Bern), Dieter Heller (at that time in Bayreuth) and Henk Breimer (Tilburg), a transdisciplinary network was founded with the informal name of "European Group of Scientists active in Eye Movement Research." It was joined by numerous scientists from various research areas, all using eye movement registration as a research tool and developing models based on oculomotor data over a wide range of phenomena, from the neurophysiological over the perceptual to the cognitive level.

The group's goals have been to facilitate the exchange of information about current research, equipment, and software, and to organize a conference every two years at a different location around Europe.

- ECEM 1, 1981, September 16-19, Bern, Switzerland
- ECEM 2, 1983, September 19-23, Nottingham, UK
- ECEM 3, 1985, September 24-27, Dourdan (Paris), France
- ECEM 4, 1987, September 21 - 24, Göttingen, Germany
- ECEM 5, 1989, September 10-13, Pavia, Italy
- ECEM 6, 1991, September 15-18, Leuven, Belgium
- ECEM 7, 1993, August 31-September 3, Durham, UK
- ECEM 8, 1995, September 6-9, Derby, UK
- ECEM 9, 1997, September 23-26, Ulm, Germany
- ECEM 10, 1999, September 23-25, Utrecht University, the Netherlands
- ECEM 11, 2001, August 22-25, Turku, Finland
- ECEM 12, 2003, August 20-24, Dundee, Scotland
- ECEM 13, 2005, August 14-18, Bern, Switzerland
- ECEM 14, 2007, August 19-23, Potsdam, Germany
- ECEM 15, 2009, August 23-28, Southampton, UK

ECEM 2011 in Marseille

It was a real honour and a great pleasure to welcome more than 500 delegates to Marseille for the 16th edition of the European Conference on Eye Movements. The series of ECEM conferences started in 1981 under the auspices of Rudolf Groner in Bern. This year, we therefore celebrated the 30th Anniversary of ECEM. For this special occasion we had as a special guest Rudolf Groner, and honoured Alan Kennedy and George W. McConkie for their contributions to our field in two special symposia. We had the pleasure of listening to six keynote lectures given respectively by Patrick Cavanagh, Ralf Engbert, Edward L. Keller, Eileen Kowler, Rich Krauzlis and Gordon E. Legge. These exceptional scientific events were nicely complemented by all submissions, which made the ECEM 2011 program a very rich and interdisciplinary endeavor, comprising 19 symposia, 243 talks and 287 poster presentations, and a total of about 550 participants. The conference opened with an address given by Denis Bertin, vice president of the scientific committee of the University of Provence, and representing Jean-Paul Caverni, President of the University of Provence. It closed with Rudolf Groner's address and the awarding of the best poster contributions by students and postdocs.

This year, three posters were awarded; the first prize was offered by SR Research, the second prize was given by the Cognitive Science Society, and the third, the Rudolf Groner Prize, was offered by the ECEM organizing committee. The conference was held on the St Charles campus of the University of Provence, and to mark the return of ECEM in Southern Europe, many events including lunches, coffee breaks, aperitifs and poster sessions took place outside under the trees of our campus. Luckily, the sun was with us for the five days of the conference !

Françoise, Stéphanie, Stéphane, Eric & Laurent

The Organizing Committee



From left to right: Stéphane Dufau, Stéphanie Desous, Laurent Goffart, Françoise Vitu-Thibault & Eric Castet

Françoise Vitu-Thibault (Chair)

Stéphanie Desous & Stéphane Dufau (Local Co-organizers)

Laboratoire de Psychologie Cognitive,
CNRS, Université de Provence,

Bâtiment 9, Case D, 3 Place Victor Hugo, 13331 Marseille Cedex 03

Eric Castet & Laurent Goffart (Scientific Co-organizers)

Institut des Neurosciences de la Méditerranée, CNRS, Université de la Méditerranée,
31 Chemin Joseph Aiguier, 13402 Marseille Cedex

The Organizing Team

Members of the Organizing Team helped the participants during the conference. Several of them contributed all year long to the preparation of the conference and made this event possible.



From left to right and top to bottom: Carlos Aguilar, Eléonore Ardiale, Amar Bogadhi, Soazig Casteau, Nicolas Catz, Myriam Chanceaux, Yann Etienne, Annabelle Goujon, Suzanne Hodzig, Maria Ktori, Mariel Leclere, Frédéric Lombardo, Sylvain Madec, Delphine Massendari, Andrew Meso, Rachel Ostrand, Olivier Salzburg, Claudio Simoncini, Julien Taillan, Christophe Tandonnet, Kim Uittenhove and Marina Yao-N'Dré

The Scientific Advisory Board

Members of the ECEM 2011 Scientific Advisory Board played a key role in the scientific organization of the conference. They each reviewed a number of submitted abstracts and their evaluations formed the basis of the final decisions taken by the Scientific Organizing Committee of the conference. Several members of the board also provided very helpful, informal advice and support during the preparation of the conference. Some members of the board, present during the conference, were assigned the task of evaluating the abstracts and presentations of students and post-docs applying for the best poster awards.

- Brian Corneil (University Western Ontario, Canada)
- Frans Cornelissen (University of Groningen, The Netherlands)
- Peter de Graef (Catholic University of Leuven, Belgium)
- Heiner Deubel (Ludwig-Maximilians-Universität München, Germany)
- Thomas Eggert (Ludwig-Maximilians-Universität München, Germany)
- Neeraj Gandhi (University of Pittsburg, USA)
- Jeroen Goossens (University of Nijmegen, The Netherlands)
- John Henderson (University of South Carolina, USA)
- Uwe Ilg (Hertie Institute Tubingen, Germany)
- Albrecht Inhoff (State University of New York at Binghamton, USA)
- Zoi Kapoula (IRIS, CNRS, Paris, France)
- Reinhold Kliegl (University of Potsdam, Germany)
- Simon Liversedge (University of Southampton, U.K.)
- Susana Martinez-Conde (Barrow Neurological Inst., USA)
- Anna Montagnini (INCM, CNRS, Université Marseille II, France)
- Denis Pélisson (INSERM, Université Claude Bernard Lyon 1, France)
- Ralph Radach (University of Wuppertal, Germany)
- Keith Rayner (University California at San Diego, USA)
- Erik Reichle (University of Pittsburg, USA)
- Gary Rubin (University College of London, U.K.)
- Ben Tatler (University of Dundee, U.K.)
- Jan Theeuwes (Vrije University Amsterdam, The Netherlands)
- Robin Walker (Royal Holloway, University of London, U.K.)
- Gregory Zelinsky (State University of New York at Stony Brook, USA)

Keynote Speakers



Patrick Cavanagh

Université René Descartes, Paris, France

Patrick Cavanagh was born in Canada and received an engineering degree from McGill University in 1968. An interest in artificial intelligence led to a Ph.D. in cognitive psychology from Carnegie-Mellon in 1972. He taught at the Université de Montréal in Psychology until 1989 and since then has been a professor of Psychology at Harvard, becoming in 2008 a Research Professor. Along with Ken Nakayama, he founded the Vision Sciences Laboratory at Harvard in 1990. In 2007 he accepted a Chaire d'Excellence at the Université Paris Descartes where he has established the Centre Attention & Vision.

Prof. Cavanagh's research has focused on visual neuroscience and perception, specifically motion perception, spatial vision, color vision, attentional processes, object recognition and the links between art and brain function. His work on attention — its spatial and temporal resolution (He et al., *Nature* 1996) and its tracking functions (*Science* 1992) — opened up new directions in this active field. The discovery of a motion compensation mechanism that steadies the visual world during fixational eye movements (Murakami & Cavanagh, *Nature* 1998) triggered imaging and patient studies of the visibility of microsaccades. The demonstration that motion distorts perceived position (Whitney & Cavanagh, *Nature Neuroscience* 2000) brought new interest to the question of the representation of position in the visual system. His research is currently focused on attention in normal and clinical populations and has published an interpretation of position perception in terms of attention pointers (Cavanagh et al., *TICS* 2010) and evidence for predictive attentional deployment prior to saccades (Rolfs et al., *Nature Neuroscience* 2010). He is also exploring the contribution of various features such as shadow, color, motion, and texture to representations of visual form and these experiments led to his interest in art as a source of data for neuroscience (*Nature* 2005).

Selected Publications

- Rolfs, M., Jonikaitis, D., Deubel, H., & Cavanagh, P. (2010). Predictive remapping of attention across eye movements. *Nature Neuroscience*, in press.
- Cavanagh, P., Hunt, A., Afraz, A., & Rolfs, M. (2010). Visual stability based on remapping of attention pointers. *Trends in Cognitive Sciences*, 14, 147-153.
- Cavanagh, P. (2005) The artist as neuroscientist. *Nature*, 434, 301-307.
- Whitney, D. V., & Cavanagh, P. (2000). Motion distorts visual space: shifting the perceived position of remote stationary objects. *Nature Neuroscience*, 3, 954-959.
- Murakami, I., & Cavanagh, P. (1998). A jitter aftereffect reveals motion-based stabilization of vision. *Nature*, 395, 798-801.
- He, S., Cavanagh, P., & Intriligator, J. (1996). Attentional resolution and the locus of awareness. *Nature*, 383, 334-338.
- Cavanagh, P. (1992). Attention-based motion perception. *Science*, 257, 1563-1565.



Ralf Engbert

Universität Potsdam, Potsdam, Germany

Ralf Engbert studied physics at the University of Potsdam, Germany. He obtained a Ph.D. in Nonlinear Dynamics/Statistical Physics in 1998 in the same university. In 2000, he was a Visiting Scientist at the University of Ottawa, Canada. He was then appointed in 2004 as a Junior Professor of Mathematical Modeling in Cognitive Neuroscience, at the University of Potsdam. Since 2008, he is a Full Professor of Experimental and Biological Psychology at the University of Potsdam, and since 2011, he is Speaker of the DFG Research Unit "Computational". Ralf Engbert's research interests are focused on eye movements and attention in visual information processing. A main topic of his work is eye-movement control during reading, from experimental and oculomotor aspects to mathematical modeling. Ralf Engbert is the lead author of the SWIFT model of saccade generation during reading, which was recently extended to the control of fixation durations in scene viewing and scanning task. Experimental work on reading includes misplaced fixations, oculomotor targeting of words, and parallel distributed processing of words. A second topic of Ralf Engbert's research is the investigation of fixational eye movements and microsaccades, with focus on the modulation of microsaccades by visual attention, the interaction between slow components of fixational eye movements with microsaccades, and mathematical modeling.

Keywords. Eye movements, Visual Attention, Reading, Visual Search, Scene Viewing, Fixational eye movements and microsaccades, Human motor control, Mathematical/computational modeling, Dynamical systems.

Selected Publications

- Engbert, R., & Krügel, A. (2010). Readers use Bayesian estimation for eye-movement control. *Psychological Science*, *21*, 366-371.
- Engbert, R., & Nuthmann, A. (2008). Self-Consistent Estimation of Mislocated Fixations during Reading. *PLoS ONE*, *3*, e1534: 1-6.
- Engbert, R. & Mergenthaler, K. (2006). Microsaccades are triggered by low retinal image slip. *Proceedings of the National Academy of Sciences of the United States of America*, *103*, 7192-7197.
- Engbert, R., Nuthmann, A., Richter, E. & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review*, *112*, 777-813.
- Engbert, R. & Kliegl, R. (2003). Microsaccades uncover the orientation of covert attention. *Vision Research*, *43*, 1035-1045.



Edward L. Keller

University of California, Berkeley, CA, USA

Edward L. Keller obtained his Ph.D. from the John Hopkins University, Department of Biomedical Engineering, in 1971, working under the mentorship of David Robinson. He was then an Assistant Professor, Associate Professor and Professor in the Department of Electrical Engineering and Computer Science at the University of California, Berkeley. He was the chairman of the Joint Graduate Program in Biomedical Engineering at Berkeley and the University of California, San Francisco and the Dean of Engineering Science at Berkeley. He became emeritus in 1995 when he moved to the Smith-Kettlewell Eye Research Institute. He was a Senior Scientist and Associate Director at SKERI. He retired in 2010. Edward L. Keller received several honors: Visiting Professor, Max Planck Institute for Brain Research, Frankfurt, Germany, Senior Scientist award from the Alexander von Humboldt Foundation, IEEE Fellow, Visiting Scientist, Laboratory for Sensorimotor Research, National Institutes of Health, Bethesda.

His research interests have centered on the organization of the oculomotor system at the network level using the monkey model of the human system. He began these research interests at the periphery of this system with studies of the orbital mechanics and the oculomotor neurons. With knowledge (from his laboratory and from others) of the behavior of motoneurons for saccades, smooth pursuit, vergence and fixation, he turned to the operation of the intermediate pre-motor neurons in the reticular formation and the vestibular nuclei. It was at this stage that he discovered the important saccadic control group of cells called the omni-pause neurons. Subsequently, he had the good fortune to work for a year with Wolfgang Precht in his laboratory in Frankfurt where he was introduced to the wonders of eye movement control by the cerebellum. Following work on the cerebellum he became interested with his colleague, James McElligott, in the role played by norepinephrine in aiding neural plasticity of the vestibuloocular reflex. He then returned to studies on the visual pathways from cortex to the brain stem and cerebellum underlying the control of smooth pursuit. During a following sabbatical leave he worked with Michael Goldberg at the NIH, a period which began his long term interest in the superior colliculus. Along with studies of the neural control of target selection and saccades by collicular neurons, he began a series of attempts to explain the operation of the saccadic system with distributed neural network models. Finally, with the help of his colleague, Kyoung-Min Lee, he extended his interest in the oculomotor system to the cognitive level with studies in the cortical frontal eye fields.

Selected Publications

- Keller, E.L. & Robinson DA. (1971). Absence of a stretch reflex in extraocular muscles of the monkey. *J Neurophysiol.*, 34, 908-19.
- Keller E.L. (1974) Participation of medial pontine reticular formation in eye movement generation in monkey. *J Neurophysiol.*, 37, 316-32.
- McPeck, R.M. & Keller, E.L. (2004). Deficits in saccade target selection after inactivation of superior colliculus. *Nature Neuroscience*, 7, 757-763.
- Arai, K. & Keller, E.L. (2005). A model of the saccade-generating system that accounts for trajectory variations produced by competing visual stimuli. *Biol. Cybernetics*, 92, 21-37.
- Lee, K.-M. & Keller, E.L. (2008). Neural activity in the frontal eye fields modulated by the number of alternatives in target choice. *J.Neurosci.* 28, 2242-2251.



Eileen Kowler

Rutgers University, Piscataway, NJ, USA

Eileen Kowler earned her doctoral degree in Psychology from the University of Maryland in 1978, and went on to do postdoctoral research at New York University from 1978 to 1980. She joined the faculty at Rutgers University in 1980, where she now holds the rank of Professor II, and serves as Associate Dean of the Graduate School. She heads the Rutgers Core Curriculum in Interdisciplinary Perceptual Science, a program funded by the National Science Foundation that combines graduate training in psychophysical and computational approaches to perception in humans and machines. Kowler received the Warren Susman award for excellence in teaching in 2008. She serves on the editorial boards of the *Journal of Vision* and *Psychological Review*, and was Section Editor for Behavioral Physiology and Visuomotor Control for *Vision Research* from 1995 until 2004. She edited *Eye Movements and Their Role in Visual and Cognitive Processes*, Volume 4 of the series *Reviews of Oculomotor Research*, in 1990, and has written recent reviews of eye movements and attention, microsaccades, and eye movements and vision.

Kowler's research centers around the influence of both cognitive and sensory factors in the control of eye movements. She has studied the role of expectations and symbolic cues in the generation of anticipatory smooth pursuit eye movements, and the role of attention in guiding both saccades and smooth pursuit. Her recent work focuses on strategies used to plan saccadic eye movements during active tasks such as search and counting, and shows that saccadic planning is characterized by preferences to sacrifice the accuracy of target selection in favor of maintaining a rapid rate of saccades.

Selected Publications

- Kowler, E. (2008). Attention and eye movements. In L. Squire (Ed.) and R. Krauzlis (Vol. Ed.), *New Encyclopedia of Neuroscience*, Amsterdam: Elsevier. (pp. 605-616).
- Collewijn, H. and Kowler, E. (2008). The significance of microsaccades for vision and oculomotor control. *Journal of Vision*, 8(14), 20, 1-21.
- Gersch, T.M., Kowler, E., Schnitzer, B.S., and Doshier, B. (2009). Attention during sequences of saccades along marked and memorized paths. *Vision Research*, 49, 1256-1266
- Wilder, J.D., Kowler, E., Schnitzer, B.S., Gersch, T.M., and Doshier, B.A. (2009). Attention during active visual tasks: Counting, pointing and simply looking. *Vision Research*, 49, 1017-1031.
- Wu, C-C., Kwon, O-S., and Kowler, E. (2010). Fitts's Law and speed/accuracy trade-offs during sequences of saccades: Implications for strategies of saccadic planning. *Vision Research*, in press.
- Kowler, E. (2011). Eye movements: The past 25 years. *Vision Research*.



Rich Krauzlis

Salk Institute for Biological Studies, San Diego, CA,
USA

Rich Krauzlis earned his undergraduate degree from Princeton University and doctorate in Neuroscience from the University of California, San Francisco. After postdoctoral training at the National Eye Institute in Bethesda, he was recruited to the Salk Institute in 1997, where he is now a Professor in the Systems Neurobiology Laboratory.

Work in Rich Krauzlis' laboratory is aimed at understanding the brain mechanisms that link motor control to sensory and cognitive processing, using a variety of state-of-the-art techniques to manipulate and monitor neural activity. One key result from his lab's work is that the superior colliculus (SC), a structure on the roof of the midbrain best known for its role in the motor control of orienting movements, contains a "priority map" that keeps track of behaviorally relevant objects in the visual field. Activity in this map is important for deciding where and when to look - prioritizing how we should physically orient to objects in our environment. But they have also found that activity in this map plays a crucial role in selecting which signals are taken into account when making perceptual judgments, even in the absence of orienting movements.

Selected Publications

- Lovejoy, LP, & Krauzlis, RJ (2010). Inactivation of the primate superior colliculus impairs covert selection of signals for perceptual judgments, *Nature Neuroscience*, *13*, 261-266.
- Nummela, S.U., & Krauzlis, R.J. (2010). Inactivation of primate superior colliculus biases target choice for smooth pursuit, saccades, and button press responses, *J. Neurophysiology*, *104*, 1538-1548.
- Haged, ZM, & Krauzlis, RJ (2010). Microsaccadic suppression of visual bursts in the primate superior colliculus, *J. Neuroscience*, *39*, 9542-9547.
- Haged, ZM, Goffart, L, & Krauzlis, RJ (2009). A neural mechanism for microsaccade generation in the primate superior colliculus, *Science*, *323*, 940-943.



Gordon Legge

University of Minnesota, Minneapolis, MN, USA

Gordon Legge received a Bachelor's degree in Physics from MIT in 1971, and a Master's degree in Astronomy from Harvard in 1972. In 1976, he obtained his Ph.D. in Experimental Psychology from Harvard. He then spent a postdoctoral year with Fergus Campbell at the Physiological Laboratory, Cambridge University. In 1977, he joined the faculty of the University of Minnesota. He is now Chair of the Psychology Department at Minnesota, director of the Minnesota Laboratory for Low-Vision Research, and Distinguished McKnight University Professor of psychology and neuroscience. Gordon Legge is a member of the editorial board of *Journal of Vision*, and recently served on the National Advisory Eye Council. He was a member of a National Research Council committee involved with the redesign of U.S. currency bills. One result of the committee's work is the large-print numerals on the new bills which are helpful to people with low vision.

Gordon Legge's research has been recognized by an NIH MERIT award, the Lighthouse Pisart Vision Award and honorary doctoral degrees from the University of Montreal and the State University of New York. It concerns visual perception with primary emphasis on low vision. Ongoing projects in his lab focus on the roles of vision in reading and mobility, and the impact of impaired vision on cortical organization. He addresses these issues with psychophysical, computational and brain-imaging (fMRI) methods. His research is currently funded by two NIH R01 grants and an NIH SBIR grant. The SBIR grant is funding a collaboration with a biomedical engineering firm to develop computerbased adaptive technology to facilitate indoor wayfinding by people with impaired vision.

Selected Publications

- Legge, G.E., Yu, D., Kallie, C.S., Bochsler, T.M. & Gage, R. (2010). Visual accessibility of ramps and steps. *Journal of vision*, 10(11), 1-1-19. <http://www.journalofvision.org/content/10/11/8>
- Liu, T., Cheung, S.-H., Schuchard, R.A., Glielmi, C.B., Hu, X., He, S. & Legge, G.E. (2010). Incomplete cortical reorganization in macular degeneration. *Investigative Ophthalmology & Visual Science*. doi:10.1167/iovs.09-4926
- Lee, H.-W., Kwon, M., Gefroh, J. G. & Legge, G.E. (2010). Training improves reading speed in peripheral vision: is it due to attention? *Journal of Vision*, 10(6), 18, 1-15. <http://www.journalofvision.org/content/10/6/18>
- Yu, D., Cheung, S.-H., Legge, G.E. & Chung, S.T.L. (2010). Reading speed in the peripheral vision of older adults: Does it benefit from perceptual learning? *Vision Research* 50, 860-869. DOI 10.1016/j.visres.2010.02.006
- Legge, G.E. (2007). *Psychophysics of Reading in Normal and Low Vision*. Mahwah, NJ & London: Lawrence Erlbaum Associates. ISBN 0-8058-4328-0

Special Guests



Alan Kennedy

University of Dundee, Dundee, Scotland, U.K.

Alan Kennedy holds a BA and PhD in Psychology from the University of Birmingham. He was a lecturer in Melbourne University from 1963 to 1965 when he moved to Dundee to take up a lectureship in Queen's College, then part of the University of St. Andrews. When the College became an independent University in 1968 he remained in Dundee as one of the five founding members of the Psychology Department. He was a Senior Lecturer then Professor of Psychology, a post he held from 1972 to 2008. He is currently an Emeritus Professor and Senior Research fellow in the School of Psychology. He has held visiting posts at Monash University, Melbourne University, The University of Provence, Aix-en-Provence, Blaise Pascal University, Clermont Ferrand and Boulogne Billancourt, Paris. His research has been supported over a period of more than forty years by grants from the UK Economic and Social Research Council, The Medical Research Council, The British Academy, The Royal Society, CNRS, The European Commission and The Leverhulme Trust. He was elected a Fellow of the British Psychological Society in 1972, a Fellow of the Royal Society of Edinburgh in 1991 and was elected an Honorary Member of the Experimental Psychology Society in 2009.

He established an eye movement laboratory in Dundee in 1973 and carried out some pioneering studies of sentence processing, helping establish eye movement recording as a primary research tool in psycholinguistics. In 1981 at a Sloan Conference he demonstrated the "blank screen" paradigm - systematic eye movements occurring in the absence of visual stimuli. This work led to an examination of the degree to which readers tag text items spatially. His discovery of parafoveal-on-foveal effects in reading led to an on-going dispute as to whether or not cross-talk of this kind provides evidence for parallel lexical processing. Recent work confirming that fact that the reader's sequence of eye movements rarely honours the correct serial order of words in text has re-opened the question of spatial indexing.

Kennedy has had several long-standing research collaborations, in particular with Alan Wilkes, Wayne Murray and Joël Pynte.

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George W. McConkie

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George, W. McConkie earned his doctoral degree in Experimental Psychology from the University of Stanford in 1966. He was appointed as Professor in the Departments of Educational Psychology and Psychology at the University of Illinois at Urbana-Champaign in 1978, and he became in 1989 Professor at the Beckman Institute for Advanced Science and Technology, UIUC. He is today Professor Emeritus at the University of Illinois at Urbana-Champaign and Senior Scholar in the College of Education at UIUC. George McConkie received several honors. He obtained a Fellowship as a Fulbright Scholar to conduct research in Taiwan in 1998 and he was awarded for his Outstanding Scientific Contribution to the Study of Reading by the Society for the Scientific Study of Reading in 1995. He also obtained a Chiang Ching-kuo Senior Fellowship from the Chiang Ching-kuo Foundation in 1999.

George McConkie is one of the few pioneer researchers of the 70's, who re-introduced the study of eye movements in reading. His hope was to provide, based on eye-movement recordings, an online index of language and cognitive processes. To this aim, he designed in collaboration with Keith Rayner, one of his former students, a new technique for making changes to the visual information displayed on a computer screen contingent upon the position of the eyes. The well-known moving-window paradigm is one example of this technique, which led him and K. Rayner to provide the first estimations of how many letters are extracted during an eye fixation in continuous reading. He proposed in 1979, his first, perceptual-span theory of eye movement control, that is the assumption that processing of information within the perceptual-span drives the eyes along the lines of text. However, over the years, he became more and more convinced that his initial proposal was wrong, that the oculomotor system has a certain degree of autonomy and is not under the direct control of cognitive processes. He and his former PhD student, S.-N. Yang, describe this new view in their Competition-Interaction model of eye movement control in reading.

George McConkie has discovered several robust eye-movement phenomena, amongst which the launch site effect with Paul Kerr, another of his former PhD students; this effect has since been at the core of many studies and models of eye-movement control in reading. He was the first with D. Zola to introduce local, word-based analyses of eye movements in children learning to read. With one of his former students, John Grimes, he reported for the first time the phenomenon of change blindness (in a conference presentation in 1992, later published in a book chapter in 1996). He has greatly advanced the understanding of how visual information is integrated across saccades, with David Zola and Keith Rayner in the early years, and later with Christopher Currie, a former PhD student, and Dave Irwin. His theoretical view of transsaccadic integration is well expressed in his saccade-target theory of perceptual stability. G. McConkie also made significant contributions to the field of scene perception as exemplified by his work with L. Loschky, one of his former PhD students. He has for many years worked in collaboration with Gary Wolverton and he has supervised a great number of students and post-doctoral students coming from all over the world, who cannot be all mentioned in this short summary.

Selected Publications

- Loschky, L.C., McConkie, G.W., Yang, J. & Miller, M.E. (2005). The limits of visual resolution in natural scene viewing. *Visual Cognition*, 12(6), 1057-1092.
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Rudolf Groner

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Rudolf Groner received a PhD in Psychology from the University of Vienna, Austria, in 1966. From 1968 - 1970 he was postdoctoral fellow at the Center for Advanced Studies in Theoretical Psychology, and subsequently visiting professor at the University of Alberta, Canada, and member of the Michigan Mathematical Psychology Program in 1969. He was appointed Professor of Psychology at the University of Bern in 1980 and chairman of the Department of Psychology from 1990. He also was Visiting Professor at Humboldt University Berlin, at University of Wollongong, Australia, at Kyoto University and Nagoya University, Japan. From 1998 - 2001 he was appointed Director of the first Swiss National Postdoctoral Program *Cognitive Psychology: Basic and Applied Aspects*. After emeritation from the University of Bern in 2007, he is now professor at the faculty of psychology at the Distant Learning University of Switzerland. In 1971 he founded the Laboratory for Eye Movement Research at the University of Bern. and in the seventies he organized several symposia on psychological processes and eye movements at German and international conferences. In 1980 he initiated, together with Dieter Heller and Henk Breimer, a transdisciplinary network called *European Group of Scientists Active in Eye Movement Research* with the purpose of exchanging information about current research, equipment and software, and organizing every second year in different European countries a ECEM conference (=European Conference on Eye Movements). Rudolf Groner organized the first ECEM 1981 in Bern, and 2005 the 13th ECEM again in Bern. Over the past 30 years he served as chairperson of the group's scientific committee which consists of the organizers of all previous ECEMs. He was editor of several books based on international conferences and ECEMs, and in 2007 he was the founder and chief-editor of the *Journal of Eye Movement Research*, assisted by a board of currently 35 editors.

Rudolf Groner's early interest involved the mathematical modeling of complex cognitive activities by modules consisting of basic perceptual and attentional processes which are measured by eye tracking. Most of his work in this and in other areas he did in cooperation with his wife Marina Groner. In their formalized theory of cognitive activity they proposed a set of axioms from which, by means of Markovian processes, probability distributions of eye movement parameters could be derived. A general hypotheses generating and hypotheses testing model was formulated, and by specifying some assumptions about the efficiency of the underlying problem solving processes, exact predictions of fixation path length and error probabilities were derived.

Another line of Groner's work involved the extension of Lawrence Stark's concept of scanpaths, where he distinguished between "local" scanpaths (operationalized as the sequence of successive fixations) which are related to stimulus-driven bottom-up processing, as opposed to "global" scanpaths (i.e. the distribution of fixations on an extended time scale) which are related to concept-driven top-down processes.

For the study of reading acquisition, Rudolf Groner and Christine Menz introduced a new experimental paradigm

where participants had to learn in the laboratory a new letter system in which the letters of the text were exchanged with artificially created characters. Eye movements were recorded during the entire learning process, and stages of the learning process as well as individual reading styles could be identified. In collaboration with Sarah Wright, Rudolf Groner extended these results to phenomena in dyslexia research.

Further work involved the investigation of visual and attentional processes in relation to motion perception and eye movement control, and the role of eye tracking and observer perspective to the perception of moving objects and human walkers. Parallel to his activity at the Distant Learning University Switzerland, in cooperation with Eva Siegenthaler, his most recent research interests are directed towards the application of eye tracking methodology to usability research, within the framework of a comprehensive model of human information processing.

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Invited Talk

A historical perspective on the saccadic system: Neurophysiology and computational models

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The oculomotor system has served as a model system for the clarification of how the brain controls precision movements. Factors that make it a model system are: It is a "one joint" system with rather simple muscles and mechanical properties. Deeper understanding of this system began with the work of David Robinson who showed, in contrast to long prevailing beliefs that the orbital mechanics could be modeled as an underdamped system, the system was heavily overdamped, i.e., it was dominated by viscosity. Based on this fact he predicted that the optimal neural signals from motor neurons to eye muscles would consist of a high frequency burst of activity that dropped to a much lower level of activity just as the eye reached a new eccentric position. The low level of activity then held the eye fixed at the eccentric position against the spring-like forces of the eye muscles. At about the same time a number of neuroscientists developed techniques to record individual neurons in the alert, behaving monkey. Using these techniques allowed them to record the activity of individual motor neurons in the monkey as these trained animals made saccadic eye movements to projected visual targets. Robinson's hypothesis was confirmed, and the motoneuron signals became known as pulse-step controls. Neuroanatomists showed which brainstem regions contained the second-order neurons that projected to motoneurons. Prominent among these areas was a region in the reticular formation named the PPRF. This information made it possible to find and record from neurons that projected to motoneurons. Explaining how the signals in these upper neurons activated motoneurons, led to a model that has been the basis for further modeling efforts that still continue to the present time. Basically the neural signals at this level can be modeled with single, lumped model neurons and the coding is all temporal. The next advances came when neuroscientists began to record from higher level neurons (in the superior colliculus and cerebral cortex) that projected to the PPRF. Here a major conceptual obstacle appeared. Neurons at these higher levels are spatially, not temporally coded. This means that distributed models are now being explored to better explain the system's organization. Most recently attempts have been made to relate neural discharge in a number of cortical areas to saccades controlled by cognitive and not visual factors.

Invited Talks

Low vision and oculomotor behaviour

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Low vision is often defined as a best-corrected letter acuity less than 6/18 (20/60) or a visual field of less than 20 deg in the better eye. According to the most recent estimates from the World Health organization (WHO), 285 million people worldwide are visually impaired, of which 39 million are blind and 246 million have moderate to severe visual impairment. I will briefly discuss the causes of low vision, its prevalence, and its characterization in terms of reduced acuity, reduced contrast sensitivity and visual-field loss. Low vision is frequently discussed in terms of its perceptual impact on reading, mobility and other everyday tasks, but the influence of oculomotor factors needs exploration. In the case of reading, for example, how effective is the oculomotor recalibration that accompanies the adoption of a nonfoveal retinal site (Preferred retinal locus "PRL") in the presence of a central scotoma? How is the pattern of reading saccades and fixations affected by the reduced visual span usually associated with low vision? In the case of vision in the 3-D environment, there is a qualitative change as we descend from normal vision to severe low vision. Normal robust 3D vision declines into a visual world of coarse image blobs, with progressive loss of depth cues and loss of diagnostic object features. How does this transition affect the interplay between context, saliency and visibility in determining the pattern of eye and head movements? I will raise questions such as these in connection with examples of research on low-vision task performance. Understanding low-vision oculomotor behavior in real-world tasks may provide new challenges for contemporary oculomotor theory, and may guide the design of low-vision rehabilitation strategies and adaptive technologies.

Prediction in saccadic and smooth pursuit eye movements

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A major obstacle to achieving accurate saccadic and smooth pursuit performance is the succession of inevitable delays along the sensorimotor pathways. To overcome the deleterious effects of such delays, eye movements display a remarkable capacity to respond on the basis of predictions. This talk will review examples of predictive phenomena in both smooth pursuit and saccades. (1) Prediction in smooth pursuit: Anticipatory smooth eye movements (smooth eye movements in the direction of the expected future motion of a target) can be triggered by high-level, symbolic cues that signal the future path of a target and may be generated by neural pathways distinct from those responsible for maintained smooth pursuit. The nature of the cue is crucial: cues that are informative, but show weak perceptual salience, are less effective. Anticipatory smooth eye movements in response to effective visual cues are found on the very first presentation, showing that the significance of the cues to the pursuit system was not a product of learning in the laboratory, but was already built into the normal functioning of the system. Anticipatory smooth eye movements are also found in individual with autism spectrum disorder. (2) Prediction in saccades: Decisions about where to aim the line of sight may be influenced by expectations about where useful information is to be found. Recent results show that expectations also effect decisions that control saccadic timing. In a novel "dot accumulation" task, in which information needed to decide when to make a saccade accrues steadily over time, decisions about how long to dwell at a given location are affected by the expected difficulty of the judgment. Taking expected difficulty into account in saccadic planning may enable efficient use of time while minimizing the cognitive load associated with decisions about when to shift the line of sight. The ability of both pursuit and saccadic systems to respond on the basis of predictions strengthens the ties between eye movement control and cognitive systems, and supports the view that one of the most important functions of active cognitive systems is to construct representations of the environment for the purposes of guiding planning of movements.

Symposium - Eye movements in people with visual impairments

The impact of fixation stability on visual function in eye disease

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The stability of fixation is reduced in many people with eye disease. Although small amounts of instability are beneficial as they can reduce Troxler fading, less stable fixation is generally thought to be detrimental to visual performance. In this presentation I will present data showing that poor fixation is responsible for up to 44% of the variance in reading speed in people with macular disease. I will also show that changes in fixation stability are associated with improvements in reading speed. Training strategies to improve the stability of fixation will be discussed. Finally, different methods of classifying fixation will be reviewed and their relative merits compared.

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Improving visual performance in the peripheral retina by modulating retinal image speed using eye-tracking

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Recent studies suggest a strong connection between fixational eye movements (FEM) and visual perception. Studies have shown that FEM might be triggered by low retinal image speed (RIS) that prevents image fading. In people with macular disease, fixating with the peripheral retina, RIS is naturally increased due to fixation instability. We conducted experiments to investigate the effect of RIS caused by fixation instability in visual performance of the peripheral retina of people with and people without macular disease. Visual acuity and/or RSVP reading speed was assessed whilst RIS was modulated by using gaze-contingent stimuli controlled by an eye-tracker. During visual acuity assessment, we failed to find any effect of RIS on fixation stability. Reading speed improved for both normal peripheral retina (23 %) and peripheral retina of people with macular disease (40 %) by reducing RIS caused by fixation instability. In conclusion, reduction of retinal image speed caused by fixation instability in the peripheral retina might be beneficial for visual performance in tasks such as reading, but the mechanism for this improvement does not seem to be improved visual acuity.

Limiting factors of reading speed with central field loss: Clinical and gaze-contingent simulation studies

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A summary of our recent studies investigating low-level visual and oculo-motor determinants of reading speed with central field loss is presented. In the first set of experiments, normally-sighted observers read with a gaze-contingent simulated macular scotoma. In the second set of experiments, all subjects had an absolute macular scotoma mostly caused by Age-Related Macular Degeneration. Both experimental paradigms provided evidence that increasing the vertical spacing between lines of text only slightly improved reading speed. This suggests that, contrary to previous findings found with the Rapid Serial visual Presentation paradigm (RSVP), crowding in the vertical dimension is not a major limiting factor of reading speed. Both sets of studies showed an inverse correlation between reading speed and fixation duration. Only clinical experiments showed that the length of the horizontal component of forward saccades is a significant predictor of reading speed. In addition, clinical studies showed that poor reading speed is associated with the presence of clusters of fixations. These clusters suggest that some letters, or chunks of letters, cause specific low-level visual problems and require a large number of fixations in order to be identified.

Visual search and fixation in patients with Age-Related Macular Degeneration (AMD)

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Purpose: We conducted three visual attention experiments to identify quantitative and qualitative differences in viewing behaviour between subjects with AMD and subjects with normal vision (control group). **Method:** In the first experiment, we varied the target-distractor-similarity, the number of items, and the presence of the target. Visual search was investigated with RTs, errors, and modelling [Wienrich et al., 2009, Journal of Eye Movement Research, 3, 1-19]. The second experiment was intended to replicate our findings from the first study using eye movement analyses. In the third experiment, we used big reticules and a letter reading task. **Results:** Subjects with AMD showed both different quantitative and different qualitative search behaviour, although differences were usually subtle in early stages of the disease. Finally, we found that big reticules helped the AMD subjects to read single letters. **Conclusion:** The results indicated disease specific search strategies for subjects with AMD. Our future research will turn to the question of which of these strategies are useful for the patients' everyday lives.

Eye movements in Glaucoma

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Glaucoma is a chronic, progressive eye disease that primarily affects peripheral vision, but if left untreated can eventually lead to irreversible blindness. It is clear that glaucoma impacts on the individual's ability to function in everyday activities such as driving and reading. However, little is known about the mechanisms that underlie these deficits and how the patient perceives their visual loss. Work in our laboratory has provided new evidence that individuals with glaucoma display differences in the frequency and duration of eye movements, and the size of area viewed in a number of real-world tasks, such as watching driving videos, and passively viewing and searching images, compared with visually healthy individuals of a similar age. These findings suggest that eye movements may provide a 'window' for establishing how patients' visual field defects impact on their real-world experience and may help us to understand at what point their quality of life is adversely affected.

Special Trustees of Moorfields Eye Hospital, International Glaucoma Association

Gaze patterns and detection performance of drivers with visual field defects

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Purpose: We are evaluating how the head and eye movement behaviors of drivers with visual field loss relate to their detection of potential hazards in various situations; here we focus on scanning when approaching intersections. **Methods:** 12 drivers with homonymous hemianopia (HH), 16 drivers with binocular central field loss (CFL) and 28 matched normally-sighted persons drove in a wide-field, high-fidelity simulator. Detection rates were determined for pedestrians that appeared just before the driver executed a left or right turn. Head-scanning patterns were recorded with a light-weight, head-mounted IR tracker. **Results:** HH drivers demonstrated compensatory strategies: the first head scan on approach to an intersection was usually to the affected side (to the right for right HH and left for left HH). For CFL and NS drivers, the first scan was usually to the left. Poorer detection rates were associated with fewer head scans, complete failures to scan to at least one side at the intersection, and inadequate head-scan amplitudes (failing to scan far enough to right or left). **Conclusions:** Head-scanning behaviors are predictive of detection performance of drivers with visual field loss at intersections. Detection and eye movement behaviors on straight and curved road segments are currently being evaluated.

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Symposium - The neural mechanisms underlying eye-head coordination in gaze shifts

Neural encoding of eye-head gaze shifts in the midbrain Superior Colliculus

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Prior to, and during, an eye-head gaze shift to a peripheral target flash, a large, localised neural population is recruited in the midbrain SC. The contribution of the eye and head to the total gaze shift varies strongly with the initial eye position, and also affects the gaze-shift kinematics. I will discuss neurophysiological evidence that supports the notion that single neurons within the SC motor map encode the trajectory and kinematics of the gaze shift by the number of spikes in their gaze-related burst. According to this simple idea, each spike generates a fixed movement contribution that only relies on its location within the motor map, and that the total gaze shift is determined by dynamic linear addition of all spike-vectors. This model makes two crucial predictions that were tested in our experiments: (1) a straight-line relation between the number of spikes in the burst and the current gaze displacement vector, and (2) SC cells have dynamic movement fields. Our recordings support both predictions and suggest that the SC controls the eye-head motor systems by a feedforward command, specifying the desired gaze trajectory. Our data also indicate that the motor map has access to eye position that modulates gaze kinematics.

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Dynamic regulation of multimodal integration in the neural control of gaze

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Motor learning is required for the reacquisition of skills that have been compromised as a result of brain lesion or disease, as well as for the acquisition of new skills. Studies in my laboratory have recently examined the linkage between neuronal responses and gaze control during the impressive recovery that occurs after unilateral vestibular loss. I will discuss our recent findings showing that motor learning is characterized by the dynamic reweighting of inputs from different modalities (i.e., vestibular, neck proprioceptive, and neck motor signals) at the level of the single neurons that constitute the first central stage of vestibular processing. Our experiments show that two types of information, which do not influence neuronal responses before lesions, have an important role during compensation. First, neck proprioceptive inputs are unmasked within one day after lesion, and play a critical role in the early stages of compensation. Second, VOR interneurons encode an efference copy signal after lesion which contributes to improving gaze accuracy during voluntary eye-head gaze shifts. Together, our findings provide evidence linking the dynamic regulation of multimodal integration at the level of single premotor neurons and behavioral recovery, suggesting a role for homeostatic mechanisms in the pathways that control gaze.

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Effects of target modality of eye-head coordination: Implications for gaze control

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A growing body of evidence indicates that the coordinated movements of the eye and head that result in gaze shifts are controlled by two partially independent pathways accessing the brain stem oculomotor circuits and more directly the motoneurons innervating the neck muscles. I will discuss behavioral evidence supporting this hypothesis from gaze shifts performed under strict psychophysical conditions that required non-human primates to orient accurately to non-predictive visual and acoustic targets. Unlike gaze shifts to visual targets, in which the eyes moved before the head, gaze shifts to acoustic targets consistently started with a head movement, which resulted in greater contribution of the head to the gaze shifts, even for movement amplitudes of less than 20-25 deg to which the head contributed very little or not at all in the visual target condition. These differences indicate that the coordinates in which the signals triggering the gaze shifts are encoded in the periphery, retinocentric vs head-centric, determine the eye-head coordination strategy used to accomplish the gaze shift. The significant differences in eye/head movement latency in the visual and acoustic target conditions suggest that information from different sensory modalities differentially accesses the hypothesized pathways before interactions take place.

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Properties of the brainstem burst generator activity during gaze shifts

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The eye velocity waveforms of amplitude-matched head-restrained (HR) and head-unrestrained (HU) gaze shifts can be quite different. The reduction in eye velocity (HU-HR) is several times greater than the head velocity. It has been hypothesized that an efferent copy of the head movement command attenuates the gain of the high-frequency burst neurons (BNs), which issue the oculomotor drive to the extraocular motoneurons. This theory also explains the often observed dual peaks in the eye velocity waveform [Freedman & Sparks, 2000, *Experimental Brain Research*, 131(1), 22-32]. We recorded BN discharge during HU and HR gaze shifts. For each neuron, the burst profile from each HU trial was compared with the burst waveform of every HR trial. The oculomotor drive was considered "identical" for the pair yielding the lowest root-mean-squared difference. For matched HR and HU trials, the peak eye-in-head velocity was substantially smaller in the HU condition, and the reduction was several times greater than the HU peak head velocity. Thus, a significant portion of the reduction in eye velocity during HU gaze shifts is imposed downstream of the BNs [Bechara & Gandhi, 2010, *Journal of Neurophysiology*, 104(2), 811-828]. The HU eye velocity waveforms identified for the matched bursts did not exhibit dual peaks. In our dataset, trials with dual peaks were consistently accompanied by a gaze-evoked blink [Gandhi, 2007, *Society for Neurosciences Abstract, Program No. 178.2*].

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Transcranial magnetic stimulation (TMS) of the frontal eye fields (FEF) in human and non-human primates

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We are developing an animal model for the effects of TMS in the oculomotor system, focusing on the FEF. Recently, we demonstrated that low current intracortical microstimulation of the primate FEF evokes a neck muscle response without saccades. Based on this, we examined neck muscle activity following TMS-FEF in humans. We delivered TMS-FEF (2 pulses at 20 Hz) just before rightward or leftward memory-guided saccades, and observed both a decrease in the contralateral saccadic reaction times, and a brief neck muscle response. Moreover, the evoked response was task-dependent, being greater when TMS was delivered to the actively engaged FEF. We have also delivered TMS to the primate FEF in this task. As in humans, TMS-FEF evoked a brief, task-dependent neck muscle response. A different experiment showed that repetitive TMS-FEF (1 Hz for 10 minutes) decreased the magnitude of visual responses on neck muscles, consistent with decreased excitability of the oculomotor system. These results demonstrate common effects of TMS-FEF in humans and non-human primates, suggest that neck muscle recordings can serve as an objective marker for TMS-FEF, and motivate predictions about the effects of TMS-FEF that can be tested directly via neurophysiological recordings in downstream targets such as the superior colliculus.

Cerebellar mechanisms for orienting the fovea toward a visual target

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During the orienting reaction, a spatial congruence is established between the source of a sensory event and the direction of gaze. The medio-posterior cerebellum (MPC) plays an important role in this sensorimotor association since its dysfunction alters its accuracy. By a series of experiments that consisted of reversibly perturbing the caudal fastigial nucleus (cFN) in the feline and primate species, we were led to identify different sub-systems for orienting the fovea toward a visual target, with and without the contribution of the head. Through their projections toward the rostral Superior Colliculi, the cFNs would adjust motor commands for directing gaze toward a target located in the central visual field. Through their projections toward premotor centers in the pontomedullary reticular formation, the cFNs would adjust the balance between excitatory and inhibitory commands for generating the proper drive to quickly and accurately orient gaze toward peripheral targets. The different deficits observed between the feline and primate species suggest strategies that depend upon the nature of the target and the neuro-morphological organization of the eye-head system. The MPC is a good candidate for compensating for different neuromuscular morphologies and anisotropies in the mechanisms controlling the triggering and execution of the orienting reaction.

Scenes I: Memory & Attention

Guiding eyes away from previous locations of information presentation impairs retrieval of semantic information

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People fixate on blank locations if relevant visual stimuli previously occupied that region of space. This so-called 'looking at nothing' phenomenon is said to be a consequence of information retrieval from an integrated memory representation. However, it is not clear whether it facilitates memory retrieval. In Experiment 1 participants were presented with four pieces of auditory semantic information. Each information was associated to one of four areas on a computer screen. After the presentation, participants heard a statement testing one information, while the computer screen was blank. Results revealed more fixations towards the area associated with the tested information, confirming looking at nothing. In Experiment 2 a red cross was presented on the blank screen either in the area associated with the tested information or in one of the other areas. Participants showed higher fixation rates for the area where the cross was presented. Retrieval performance was high when there was no cross or when the cross matched the area that was associated with the tested information. When looking at nothing was disrupted, performance declined. In conclusion, eye-movements to blank regions in space may play an active role when retrieving information from an integrated memory representation.

Eye movements during pictorial recall have a functional role, but they are not reinstatements of those from encoding

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This study investigated the role of eye movements during pictorial recall. Forty-three participants inspected complex pictures in a perceptual encoding task and subsequently recalled them while looking at a blank screen. The recall task was to orally describe the pictures from memory. Encoding and recall were performed under three experimental conditions. In a first condition of free viewing, participants were free to move their eyes both during encoding and recall. In a second condition of central encoding, participants were instructed to maintain central fixation during encoding but were free to move their eyes during recall. In a third condition of central recall, participants were free to move their eyes during encoding but were instructed to maintain central fixation during recall. Results revealed three main findings: 1) under the free viewing condition, eye movements during recall closely reflected content and spatial information from the original picture; 2) despite the central encoding condition, eye movements spread out during recall and reflected content and spatial information from the original picture; 3) the central recall condition affected and impaired the picture descriptions during recall. These results partially contradict previous studies and are discussed in relation to current literature on eye movements to "nothing".

Attention, eye movements, and memory

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The relationship between attention, eye movements, and memory is an enduring question, especially in the context of mediated message processing. Eye movements, usually employed as the indicator of attention, are postulated to be positively associated with memory, but empirical studies show disparate results. Two main issues emerge from the current literature. First, scholars have different opinions about which measure of eye movements appropriately represents attention. Most researchers support fixation duration, while some prefer fixation number. Second, research findings reveal that measures of eye movements seem not to be correlated with memory scores. Some structural features of mediated messages (e.g., salience) have even better explanatory power than measures of eye movements. This paper proposes a composite measure encompassing fixation duration and fixation number and argues that separating implicit attentional capture from explicit attentional capture is a possible way to clarify the relationship between attention, eye movements, and memory. Two experiments using flanker tasks were ran. The results find that the fixation duration on the distractor may mainly reflect implicit attentional capture and does not affect memory score. The composite measure which weights fixation duration by fixation number on the same area of interest can better predict memory score.

Incidental learning speeds visual search by lowering response thresholds, not by improving efficiency

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In the influential Guided Search Theory [Wolfe, 2007, In W. Gray (Ed.), pp. 99-119], attention is guided to a target by a combination of its bottom-up salience, and user-guided, top-down processes that seek objects sharing its features. Surprisingly, the model accurately predicts visual search data with an architecture that maintains no history of attentional deployments; it is amnesic. Nevertheless, when people search the same display repeatedly, they can incidentally learn repeated objects and search becomes faster. In the current study, we asked two questions: 1) under what conditions does such incidental learning occur? And 2) what does viewing behavior reveal about the efficiency of attentional deployments over time? In two experiments, we tracked eye movements during repeated visual search, and we tested incidental memory for repeated non-target objects. Across conditions, the consistency of search sets and spatial layouts were manipulated to assess their respective contributions to learning. Using viewing behavior, we contrasted three potential mechanisms by which experience with distractors could facilitate search speed. Results indicate that learning does not result in faster object identification or greater search efficiency. Instead, familiar search arrays allow faster resolution of search decisions, whether targets are present or absent.

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Visual search in the real world: Evidence for the formation of distracter representations

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Visual search often involves repeatedly searching the same environment for different targets. What is the fate of information about fixated distracter objects during these searches? Here, participants searched the same array of real objects for two different targets in order. We found that fixating an object when it was a distracter in the first search facilitated search for that same object when it became the target in the second search. The results suggest that the location and identity of fixated distracter objects are represented to a level that guides subsequent searches, even when this information is task-irrelevant at the time of fixation.

Searching for IOR: Waldo returns

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Visual search of complex scenes integrates top down and bottom up attentional mechanisms. One such attentional mechanism is Inhibition of return (IOR), which has been proposed to facilitate visual search by inhibiting reorienting to previously attended (yet still salient) spatial locations. IOR was originally measured following the removal of attention from a spatial location; responses to this location are slower than to other locations. Slower responses to probes presented in recently-fixated locations have since been demonstrated in a variety of visual search tasks, and this form of IOR has been related to the reduced likelihood of refixating recently searched locations during natural search. However, recent research has challenged this interpretation by showing that a tendency to saccade forward, rather than a bias to return, best characterizes the pattern of saccades during natural search. Here we show that frequent refixations of previously attended locations do occur during search. However, refixations come at a cost of increased saccadic latency, providing evidence that IOR must be overcome for these return saccades to be executed. The results suggest that IOR operates in natural search, but that top down strategies can override IOR to refixate previously attended locations.

Symposium - Applied eye-tracking methodology

The long and winding road towards reliable eye-tracking data analysis

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Eye-tracking has been used in psychological research for more than 70 years. Despite of this fact, it appears that there still are many fundamental methodological issues which have not been solved in an acceptable way. As an introduction to the eye-tracking methodology symposium, we propose an overview of the various issues that appear in the preprocessing steps of eye-movements analyses, including fixation identification, systematic error correction, hit detection and gaze features computation. For each step, we present the problematic as well as the usual solution(s) found in the literature. Moreover, we propose novel alternatives for two of these points. We first present a very general probabilistic technique to estimate and correct systematic errors in gaze positions. This method can be applied to various experimental setups and can also be used to estimate space-varying or time-varying errors. Secondly, we offer a probabilistic alternative to the usual closest neighbor solution for hit detection. This new solution aims to avoid some biases inherent to the classical solution when analyzing complex stimuli. Finally, we briefly discuss the implications of these methodological issues on the results of statistical analyses of eye-movements.

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A tool to measure the accuracy and precision of eye-trackers

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Lack of accuracy can be critical for gaze contingent systems or if the stimuli are closely spaced or irregularly distributed [Zhang & Hornof, 2011, BRMIC submitted]. A tool was developed that expects participants to click on tiny dots to force them to look very carefully at the mouse pointer and position it very steadily prior to a click. Gaze data is analysed to calculate accuracy and precision at various positions on the screen. Variables such as grid dimensions, gaze angles, framerate, recording interval and type of feedback can be controlled by the user. Calculated results are saved in csv format and raw gaze data is also available. The tool also illustrates the improvement in accuracy that can be gained through a regression model. While it is normally accepted that the accuracy of remote video-based eye-trackers lies between 1° and 2° [Hansen & Ji, 2010, IEEE Transactions on Pattern Analysis and Machine Intelligence, 32(3), 478-500], this procedure succeeds to improve the average accuracy across the entire screen to less than 0.8° for all participants on various models of Tobii eye-trackers with the accuracy of some individual recordings being as low as 0.3° across the entire screen.

Pros and cons of a cheap 50Hz remote eye tracker

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Despite eye tracking is gaining popularity, it is still expensive (+25 K€). There are cheap 50 Hz eye trackers available (\pm €5000), but these have disadvantages. What can and cannot be measured with cheap eye trackers? Low frequency eye trackers are not able to track the eyes carefully during saccades (saccades contain frequencies up to 75 Hz) and therefore fixation detection is preferred instead of saccade detection. To be able to extract useful information from raw data an adaptive fixation detection algorithm is suggested. Applications of 50 Hz eye trackers will be shown. Cheap eye trackers are suitable for Area of Interest analysis, reading (only large fonts), visual search and scene viewing. They are not suitable for evaluation of saccade dynamics, signals containing both pursuit and saccades, micro-saccades, vergence and cannot be used for gaze contingent displays. Furthermore it will be shown that the use of a chinrest and careful instruction of subjects may improve data quality significantly.

Beyond AOIs: Classification and prediction methods in gaze data analysis in biometrics, problem solving, and interaction

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Typical past eye-tracking data analyses relied on spatio-temporal aggregation of the eye-tracking measures. An area of interest would be defined as a collection of data within a predefined time-segment, measures of mean and deviation would be computed, and traditional statistical methods such as pair-wise comparisons would be performed to investigate the phenomena that are believed to generate the data. This type of analysis is suitable for measures such as "fixation time spent on an area" and "number of fixations" that bear an intuitive connection to the visual attention of the user. The method has been criticized, for too coarse granularity, smoothing out individual differences, difficulties with treating missing data, and for inability to explore the nuances of visual attention and its connections to high-level behavior and internal processing. Eye-tracking data can also be looked at as signals and we present three cases of applying computational approaches to analyze eye-tracking data on lower levels than before. We apply various machine learning methods and we study combinations of multidimensional features to better evaluate the behavior of the user and the links between visual attention and 1) personal traits (biometric identification), 2) problem solving (strategy and skill inference), and 3) intent to interact.

Event detection in data with static and dynamic stimuli

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Smooth pursuit eye movements occur when the eyes are following a moving object. Today, most algorithms are designed to detect fixations and saccades, but very few consider smooth pursuits. In data recorded with dynamic stimuli, it is important to detect smooth pursuits which otherwise may render the analysis of fixation and saccade properties difficult. We therefore propose an algorithm that is able to detect fixations, saccades, and smooth pursuits. In addition, it separately identifies glissades; a wobbling eye movement at the end of many saccades. The algorithm is evaluated using a database containing data with both static stimuli in the form of texts and images, and dynamic stimuli including video clips and points moving in different directions and with different speeds. The performance of the algorithm is evaluated with respect to the percentage of time in each event type for static and dynamic stimuli, respectively. Preliminary results show that the algorithm, independently of the type of stimuli is able to detect and distinguish between the four different types of events. Accurate detection of smooth pursuit eye movements provides new possibilities for the investigation on how moving objects are seen and understood.

All data in this study was recorded at Lund Humanities Laboratory, Lund University, Sweden.

Film making practice and oculomotor behaviour: An eye tracking perspective

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A class of theoretical speculations originating in film theory have been until very recently proven elusive in regard to attempts for empirical confirmation. Recent advances in moving images research have allowed a number of these speculations to be investigated using eye tracking methodologies. Smith offers a succinct account of existing knowledge in regard to how viewers perceive moving images [Smith, 2010, In Goldstein (Ed.), pp. 458-461]. Research in low level features is currently addressed within cognitive and perceptual psychology frameworks. Film-making practitioners need methods to examine complex features of moving images. In eye tracking research related to dynamic visual scenes, one of the main issues remains the sampling resolution of the eye tracking instrument as it determines the maximum amount of information that can be acquired for each frame in regard with a subject's oculomotor behaviour. A type of computer generated moving image stimulus is introduced that offers a specific benefit; it allows us to examine behavioural patterns that are associated with overt shifts of visual attention using a standard 50 Hz sampling resolution eye tracker. A Bayesian approach is used to determine if oculomotor behaviour is affected according to film theoretic speculations.

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Special Symposium in Honor of Alan Kennedy – Spatial coding and eye-movement control

Visual processing and spatial memory co-determine the accuracy of short and long range regressions in reading

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We have shown previously that the distance effect typical for progressive reading saccades is completely absent in short range interword regressions, which tend to go to the target word center irrespective of word length and launch distance [Radach & McConkie, 1998, In G. Underwood (Ed.), pp. 77-100]. Less clear is the situation for long range regressions, with Kennedy et al. [2003, In Y. Hyönä et al. (Eds.), pp. 193-210] suggesting high precision based on spatial coding, while Inhoff & Weger [2005, *Memory & Cognition*, 33(3), 447-461] propose a less accurate mechanism primarily based on visual and linguistic information. Our present work compared regressions with near vs. far launch distances and sought to clarify which type of information is used in their programming. Eye movement contingent display manipulations were used to shift lines of text before regressions were executed, allowing to determine to what extent their amplitude is based on spatial memory vs. visual information acquired during saccade preparation. Results indicated that readers used different regression strategies based on task conditions, a single shoot (and correct) strategy vs. a backward scanning routine with multiple intervening fixations. We suggest that amplitudes of long range regressions are indeed partially based on accurate spatial coding and that the quality of spatial memory may co-determine the decision to use a single shoot vs. backtracking strategy.

Eye guidance and the binding of lexical and spatial representations during reading

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A spatial cuing technique was used to examine readers' binding of lexical and spatial representations in working memory. After the reading of two-line passages of text, participants were asked to determine whether an individually presented word had appeared in the previously read passage. The presentation of the to-be-classified word was accompanied by the onset of a visual cue that occupied the word's location in the previously read sentence on valid trials and a different location on invalid trials. No spatial cue was shown on control trials. The results revealed a robust effect of a word's prior sentence location on classification performance. The presentation of a visual cue influenced eye movements during the classification task, but the effect of its validity was not clear cut.

Interactions between visuo-spatial memory and saccade target selection during scene perception and search

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Memory for the locations of objects in scenes is a central component of visual search and enables the efficient execution of everyday visual tasks. Although there is compelling evidence that location memory can facilitate search for objects that have previously been the target of search, evidence is equivocal as to whether object information acquired incidentally (e.g., when an object is fixated as a distractor) generates a spatial memory trace that can improve later search efficiency. In the present study, we used a repeated search task. Eye movements were monitored as participants searched through photographs of natural scenes. On each trial, participants searched sequentially within a particular scene for multiple target objects. Searches for objects early in a trial significantly improved the efficiency of searches for objects later in a trial, indicating that object-location information acquired incidentally (during search for a different object) is reliably retained and can be used to guide the eyes to target locations.

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Selection within visual memory representations activates the oculomotor system

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Humans tend to create and maintain internal representations of the environment that help guiding actions during the everyday activities. Previous studies have shown that the oculomotor system is involved in coding and maintenance of locations in visual-spatial working memory. In these previous studies observers had to remember a location which was present in the outside world (remembering the location of a dot presented on the screen). The present study extended these findings by showing that the oculomotor system also codes selection of a location from an internal memory representation. Participants first memorized two locations and after a retention interval selected one location for further maintenance. The results show that saccade trajectories deviated away from the ultimately remembered location. Furthermore, selection of the location from the memorized representation produced sustained oculomotor preparation to that location. The results show that the oculomotor system plays an active role in representing visual memory. Besides coding and maintenance of spatial information in visual working memory, it is also flexibly used for coding locations selected from representations that are no longer present in the outside world.

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Spatial coding during memorizing and executing complex instructions

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We investigated the spatial coding of multiple object and goal locations by recording spontaneous eye movements of healthy adults in an assembly task. Participants heard 3-8 consecutive instructions, each of the form "move [object] to [location]". Instructions were only to be executed after a go signal, by manipulating all 3-8 objects successively with a mouse. Participants re-inspected previously mentioned objects already while listening to further instructions. This rehearsal behavior broke down after 4 instructions, coincident with participants' assembly span, as determined from subsequent execution accuracy. These results suggest that eye movements while listening to complex assembly instructions reflect memory rehearsal of object and goal locations and predict successful instruction execution.

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Long-range regressions during oral reading

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How precise is the spatial code built during reading? There is ample evidence that readers know the location of information in a text with above-chance accuracy. It has been argued that this spatial information is precise enough to enable long-range regressions directly to the location of information needed for answering a question about a previously read text even after the screen has been erased. The conditions for the occurrence of such direct and precise long-range regressions are not well understood and are still the topic of experimental research. As usual, differences between experimental tasks, instructions, and perceived task demands are likely sources of these disagreements. Here we show that speech errors during oral reading trigger highly accurate long-range regressions to the misspoken word. We will discuss these results from the perspective of the functional role of a precise spatial code in this situation and link the results to differences between eye-movement control during oral and silent reading. We also propose that experimental induction of oral reading errors may open a window of opportunity for a better understanding of the role of the spatial code for eye-movement control during reading.

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Between-word regressive saccades to and from words of low predictability

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Saccades moving the eyes back to previous words in a text (between-word regressive saccades) are one of the most poorly understood facets of eye movements in reading. Given empirical evidence to date, at least five theories for the primary driver of between-word regressive saccades are still tenable, including theories of motor-error correction [Shebilske, 1975, In Massaro (Ed.), pp.291-311], oculomotor strategy [O'Regan & Lévy-Schoen, 1987, In Coltheart (Ed.), pp.363-383], incomplete lexical processing [Engbert et al., 2005, *Psychological Review*, 112, 777-813], integration-failure [Reichle et al., 2009, *Psychonomic Bulletin & Review*, 16, 1-21], and input-representation confidence falling [Bicknell & Levy, 2010, *ACL Proceedings*, pp.1168-1178]. Here we provide a systematic mixed-effects regression analysis of the factors influencing the likelihood of between-word regressive saccades in a relatively controlled subset of a large eye movement corpus [Kennedy & Pynte, 2005, *Vision Research*, 45, 153-168]. We find that between-word regressive saccades are most likely when origin and target words are of low predictability given the preceding context, a result contravening motor-error correction, oculomotor strategy, and incomplete lexical processing theories while lending support to integration-failure and confidence-falling theories. Among regressive saccades, these variables more strongly predict one-word than longer-range regressions, suggesting these may arise from quite different sources.

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Symposium - Orienting the gaze towards prediction

Saccadic and smooth components of ocular pursuit apparently obey different rules for prediction of direction changes

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When humans pursue a target moving with a triangular waveform composed of alternating constant duration ramps they can store timing information within a few cycles and start to initiate directional changes of smooth eye movement before target direction changes. More surprisingly, this predictive behaviour occurs even when alternating ramps have randomised timing, but timing of predictive deceleration is then dependent on stimulus timing history and is thus dependent on the range of ramp durations within the stimulus. Examination of overall eye displacement (smooth plus saccadic) for both predictable and randomised stimuli shows that despite considerable smooth eye velocity changes prior to direction changes, overall eye position remains close to the target until after the stimulus direction change as a result of corrective saccadic activity. Measurement of amplitude and direction of final saccades associated with each stimulus direction change indicates that over 95% of saccades can be positively classified as corrective, not predictive. These results suggest different predictive rules for saccades and smooth pursuit in the absence of deceleration cues. It appears that cognitive control of eye position is retained throughout each ramp even though smooth eye velocity may decline significantly under the influence of relatively low-level effects of timing history.

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Direction estimation during smooth pursuit eye movements

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In order to keep the eyes on a moving target in a noisy environment, the smooth pursuit system needs to make assumptions about target direction and to anticipate future target locations in space. We show how early cues presented when target direction is still uncertain can cause erroneous predictions of the target's future location, thus misguiding initial target-driven pursuit and perception. Later on during pursuit, when veridical target direction is resolved, online correction results in a perceived bend in target direction. We also show how pursuit might anticipate the direction of a moving target by relying on assumptions about its 'inertia': we tested the ability of pursuit and perception to integrate motion signals across large areas of the visual field and segment these from the background. We found that both steady-state pursuit and perception were influenced most by perturbation angles close to the angle of the main motion, indicating a narrow bandwidth of direction tuning for both responses. Therefore, the system tolerates only gradual changes in target direction and readily discards vectors moving in more eccentric directions. We argue that pursuit inherently expects a target to keep moving in the same direction without making large and sudden changes

Human anticipatory smooth eye movements as a probe for statistical learning

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Sensory expectations can have a great impact on oculomotor control, giving rise to shorter reaction times and to anticipatory eye movements towards a predicted target location or motion direction. Interestingly, when predictive information about target motion is affected by uncertainty, the pattern of direction, speed and timing of anticipatory smooth eye movements (aSEM) depends on the statistics of the sensorimotor events across trials. In other words, I suggest that oculomotor anticipation can be viewed, under particular conditions, as a probe of statistical learning. I will review recent results indicating that the distribution of aSEM depends parametrically upon the probability of occurrence of different target motion characteristics (speed, direction). In particular I will focus on how the encoding of statistical properties in the pattern of aSEM can be generalized to different types of distribution (binomial, gaussian). Second, I will show that aSEM are also sensitive to the higher-level statistics of sensorimotor events, such as the conditional probability of a particular motion direction given a particular cue, thereby excluding a simple explanation in terms of motor facilitation. Finally, I will analyze the buildup, across trials, of such statistically-based anticipatory activity and compare it to models of optimal integration of information.

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Impulsivity and individual differences in anticipatory eye movements

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Impulsivity is the tendency to act without forethought. This personality trait is commonly used in the diagnosis of many psychiatric diseases, using written questionnaires. However, answers to questions might be subject to biases and interpretations. In order to alleviate this problem, eye movements could be used to study differences in decision processes related to impulsivity. We investigated correlations between impulsivity scores obtained with UPPS questionnaire in healthy subjects and characteristics of their anticipatory eye movements in a simple smooth pursuit task. This questionnaire distinguishes four independent dimensions of impulsivity: Urgency, lack of Premeditation, lack of Perseverance, and Sensation seeking. The same subjects took part in the oculomotor task that consisted of pursuing a target that moved in a predictable direction. This task reliably evoked anticipatory saccades and smooth eye movements. The percentage of anticipatory responses and characteristics of eye movements were significantly correlated with UPPS scores. The specific correlations between distinct UPPS factors and oculomotor anticipation parameters support the validity of the UPPS construct and provide neurobiological explanations for impulsivity. In conclusion, we suggest that the oculomotor approach of impulsivity that we initiated in the present study could help to bridge the gap between psychiatry and physiology.

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How optimal are human fixation selection strategies?

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Fixation selection has been studied extensively, and is commonly thought to be directed by salient stimuli [Itti & Koch, 2000, *Vision Research*, 40, 1489-1506]. Saliency is a good predictor for passive viewing situations; however information theoretic models provide a framework for understanding the active collection of visual information. In a timed shape discrimination task, we demonstrate that the eyes are directed to reduce local uncertainty about the orientations of the shape contour, a mostly efficient yet sub-optimal strategy [Renninger, et al., 2007, *Journal of Vision*, 7(3), 6]. When searching for a single target, gaze may shift optimally [Najemnik & Geisler, 2005, *Nature*, 434, 387-391], but when observers search for multiple targets, single target search strategies persist and are inefficient for the task [Verghese, 2010, *Society for Neuroscience*]. Under conditions of central vision loss, fixation selection appears to be directed as if vision was normal, again resulting in inefficient information gathering [Renninger, et al., 2008, *Journal of Vision*, 8(6), 641]. These findings lead us to conclude that fixation selection strategies are not optimal in general. We conjecture that this is due to a lack of evolutionary pressure as eye movements are quick and relatively inexpensive to execute.

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Activities in primate striatum and prefrontal cortex during memory-guided and reward-guided saccades

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A memory-guided saccade task requires subjects to remember visually cued locations to make accurate saccades after delay. If reward outcomes are variable and predictable, saccade behavior would be modified according to the expected reward. Interestingly, the major stations in the brain's saccade network are known to be sensitive to reward expectation. Thus, it is conceivable that reward information and saccade signals are integrated during action planning. Recent primate single-unit research supports this hypothesis. We used a memory guided saccade task in which only one direction was associated with reward. When the rewarded direction was the same as the cued saccade direction, the animal could obtain reward. Otherwise, the animal had to make a saccade to the cued direction without expecting reward. Single-neuron activities in the primate lateral prefrontal cortex and caudate nucleus were contrastive such that prefrontal neurons maintained tuning to the cue direction independent of the reward direction, whereas caudate neurons lost the spatial tuning being interfered with the reward direction. Different types of spatial tuning in the two brain areas may contribute to different types of goal-directed behavior.

Gaze & Action

Dynamic spatial asymmetries in overt attention depend on handedness, but not gender, spatial frequency of image type

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Neuropsychological and neuroimaging studies demonstrate hemispheric asymmetries in the control of visual attention. Here we investigated whether these are expressed in the behavior of normal subjects under natural conditions and investigated contributions of different processing channels. We recorded eye-movements of human subjects viewing natural visual stimuli. To control for potential confounds of asymmetric image content, we compared stimuli in original and mirror-reversed conditions. (1) In the initial phase of free exploration fixations are strongly biased leftward (0-1.5s, >20% of all fixations). This is followed by a small but persistent rightward bias (1.5-6s, ~5% of all fixations). This pattern was independent of image category (natural, landscape, fractals, or noise) and subject gender (n=44, all right handed). (2) Probing the contribution of different lateralized cortical pathways we tested the role of visual spectral content and handedness. Neither high- nor low-pass filtering of images changed the bias pattern. (3) However, in contrast to right-handed subjects left-handed subjects showed no clear bias. Our results demonstrate a robust and strong asymmetric spatial bias in free-viewing behavior and show that it is independent of image content but related to the same cerebral asymmetry responsible for hand dominance.

When the type of motor output matters: Line bisection by eye and by hand reveal opposite bisection biases

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Manually bisecting solid lines reveals leftward bisection errors for most right-handed people; bisecting letter lines reveals rightward bisection errors. Both types of pseudo-neglect have been linked to an interaction between the visuo-spatial distribution of attention and lateralised processing of the specific stimulus quality of the to-be-bisected material. Eye-movements with their close link to visual attention should therefore reflect the same hemi-spatial biases when fixation is used to indicate the line's subjective midpoint. However, this assumption has recently been challenged by results showing rightward biases for eye fixations to bisect lines under conditions expected to produce leftward biases in manual bisection [Elias et al., 2005, *Brain and Cognition*, 59(3),296-298]. In a series of three experiments, we here investigated whether biases for bisecting solid or letter lines depend on the type of motor output used for bisection. In the same participants, manual bisection (paper & pencil or touch screen) led to relative rightward biases for letter lines and leftward biases for solid lines, while bisection by fixation revealed, mirror-reversed, relative leftward biases for letter lines and rightward biases for solid lines. Implications of these findings for models on vision and action, and for the neural mechanisms underlying pseudo-neglect are discussed.

We thank Dr Colin Davis for providing us with wordfree letter lines.

Multiple roles for eye movements in rapid reaching to peripheral targets

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A saccade is typically deployed just before the hand during a goal-directed movement. Eye and hand landing positions are usually spatially and temporally correlated, yet underlying mechanisms remain unclear. Is a saccade deployed to gather information about the target location to refine reaching? We investigated the contribution of target visibility on eye-hand coordination. We varied target eccentricity (range: 2-12°) and target duration (100ms or on until touch) using a block design. Participants made a rapid point to a target on a touchscreen and we measured eye position throughout the trial and finger endpoint position. Saccade latencies remained consistent and reach latencies increased as a function of target eccentricity, suggesting target visibility is critical for eye-hand coordination. In both target duration conditions, saccade error was more strongly correlated with hand error at 10-12° than at 2°. In the absence of updated visual information (brief target), the saccade still confers a benefit on pointing compared to conditions with no saccade; suggesting that eye position signal and/or attentional deployment may be used to refine target localisation. Altogether, our results suggest a common map of visual space is used to coordinate eye and hand.

Eye-movements of patients with Parkinsonian syndromes during walking: A method for (differential) diagnosis?

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Progressive Supranuclear Palsy (PSP) is a progressive neurodegenerative disease characterized by postural instability, frontal dementia and supranuclear gaze palsy. It is widely misdiagnosed as Parkinson's disease (PD), but an early differential diagnosis is essential for adequate treatment. To compare visuomotor behavior, we asked PSP-patients, PD-patients and healthy controls to walk up and down a corridor, while their eye movements were recorded with a wearable gaze-tracking system (EyeSeeCam). PSP-patients showed significantly reduced saccade amplitudes, and significantly reduced saccade velocities as compared to PD-patients and controls. PSP-patients made substantially fewer voluntary saccades in the vertical plane. Some PSP-patients never showed saccades larger than 15 degrees and several were virtually unable to track a stationary target while walking. Despite substantial inter-subject variability in PSP-patients, saccade properties suffice to distinguish PSP-patients from PD-patients. Hence our findings provide robust oculomotor markers to identify PSP from PD. Especially, when combined with more sophisticated paradigms (e.g., memory-guided viewing) these markers will likely complement fMRI and EEG in basic research on the neuronal circuitry underlying the disease(s). As eye-movement patterns are readily measurable in clinical practice, our findings also hold the promise to eventually allow an earlier and more clear-cut differential diagnosis between PSP and PD.

Visual spotting in a complex skill in gymnastics

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We examined the visual spotting hypothesis in gymnastics [Davlin et al., 2001, *Perceptual and Motor Skills*, 93, 465-471]. N = 6 gymnasts performed backward dismounts after giant swings from the high bar with an increasing angular velocity about the somersault axis: 1) single somersault in layout position, 2) double somersault in tucked position (traditional technique), and 3) double somersault in tucked position (scoop technique). A wireless eye-tracking device in combination with a movement analysis system was used to measure participants' eye movements and movement kinematics. Gymnasts exhibited more fixations, $F(1.60, 8.00) = 12.88$, $p < .01$, with longer durations, $F(1.33, 6.62) = 19.42$, $p < .01$, during the single somersaults compared to the double somersaults. When performing the scoop technique, gymnasts showed less fixations during the giant swing compared to the traditional technique, $F(1.52, 7.61) = 4.80$, $p < .05$. There were no significant differences in landing stability. Gymnasts use visual spotting even when movements are very dynamic in nature. We conclude that visual information pickup is functional for movement execution in complex skills in gymnastics.

Effects of concurrent vocal responses on eye movements

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The simultaneous execution of two responses is known to cause interference, a finding that was also demonstrated for saccades and manual responses. However, it remained an open question whether corresponding interference is based on shared physical characteristics of responses in both tasks (i.e., when both responses involve left/right movements), or on shared abstract concepts (i.e., when both tasks involve the cognitive concepts of left/right). In the present study, participants responded to lateralized auditory stimuli by saying "left" vs. "right" (vocal task), by executing a left vs. right saccade (saccade task), or both. Results indicated that both vocal responses and saccades exhibited significant dual-response costs. We propose that physical overlap of response dimensions is not necessary for the occurrence of dual-response interference. Implications for more complex tasks involving oculomotor control (e.g., oral reading) will be discussed.

Innovative Methodologies & Technologies

Systematic gaze position influences on pupil size measurement: Analysis and correction

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Pupil dilation is used to assess cognitive effort, but pupil size measurement is prone to changes in gaze position. The present study used sentence reading as a stand-in paradigm for tasks where gaze position changes are unavoidable. For the first investigation of the gaze position influence we used an artificial eye model with a fixed pupil size and found that the measured pupil size altered systematically with gaze position. Second, z-string scanning was used as a control task which results in a similar eye movement pattern when compared to sentence reading but is not cognitively demanding. The pupil responses of both the artificial eye measurement and the z-string scanning task were nearly identical. For the correction of the influence of gaze position in the pupil response during sentence reading we used functions which were derived from the artificial eye and z-string data. The corrected sentence reading data, importantly, revealed a typical pupil response which was predominantly found in the literature and showed an increased dilatation of the pupil compared to the cognitively less demanding z-string scanning.

JVideoGazer - Towards an automatic annotation of gaze videos from natural scenes

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Modern mobile eye-tracking systems record participants' gaze behavior while they operate in an unrestricted environment, often haptically manipulating complex objects of interest. These mobile systems can be easily set up and operated. However, the gained freedom is paid for with a difficult and cumbersome analysis of the stored gaze data, as the recorded scene videos are individually different and have to be manually annotated, sometimes frame-by-frame, to mark regions of interest. This very time consuming and error-prone process prevents the use of eye-tracking techniques in various areas of application. In order to overcome these problems, we developed a new software for fully- and semi-automatic annotation of gaze videos. After an initial manual selection of target objects or regions, several object detection and tracking algorithms which are invariant to translation, scale and rotation can be applied to complete the annotation automatically. We evaluated our software by comparing its results to those of a manual annotation using scene videos of a typical day-by-day task. Results show that JVideoGazer provides a reliable automatic video analysis even under challenging recording conditions and thus significantly speeds up the annotation process.

Simultaneous eye tracking and fast Dynamic EEG current source density imaging for assessment of commercials or web sites

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Eye tracking was used earlier for evaluation of commercials. But the question remained whether the visual contact induced functional changes within the brain. We now report on a combination of two well-accepted methodologies linked by a trigger: Eye tracking and Computer Aided Topographical Electro-Encephalo-Metry (CATEEM). Thus, it became necessary to speed up our technology of brain mapping. For objective quantification of EEG, raw signals had to undergo a Fast Fourier Transformation (FFT). Here a set of parameters exists (sampling-rate and sweep-length), where elementary single modes represent earlier defined frequency ranges by a single wave (natural frequency). Sweep-length is now 0,3636 seconds instead of 4 seconds. Sampling rate of 128 Hz changed to 176 Hz. Elementary frequency ranges for quantitative analysis are now 1,375 Hz - 4,125 for delta, - 6,875 Hz for theta, - 9,625 for alpha1, - 12,375 Hz for alpha2, - 17,875 for beta1 and - 34,375 for beta2. Fast dynamic analysis revealed single sweeps with extremely high spectral delta and theta power at frontal electrodes, when eyes targeted at pitch-perimeter advertising during sport TV. The pattern corresponded to data averaged for longer periods (minutes) recorded earlier during reading.

Cross-modal human-machine interaction: Combining cortical activity and gaze control

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We propose a brain-eye computer interface (BRECI) that implements human-machine interaction based solely on brain signals and oculomotor measurements. BRECI is used to control a car racing simulator fully hands-free, allowing for game play purely by "look and think". More specifically, our system monitors and analyses EEG data and detects typical cortical signals from a motor-imagery task that players generate by imagining a movement of the right or left hand. In addition, the player's eye movements operate an accelerator via a gaze-contingent slider bar that adjusts the driving speed. EEG and eye-movement data are processed on-line in real-time so that BRECI provides unrestricted control of the computer with no noticeable delay in response to user actions. A system evaluation demonstrated that although players achieved significantly slower race times with BRECI than with manual control via, for example, keyboard or mouse, they were satisfied with the novel input method. In summary, we consider the present system as a convenient, novel way of controlling (not only) computer games driven by the player's mind and attention.

The study was funded by the German Research Council (DFG, Center of Excellence Cognitive Interaction Technology, EXC 277).

Integration of an eye tracking system in prosthetic vision simulator: Study of mobility tasks performances

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The loss of autonomy when moving in an unknown environment is one of the major concerns faced by blind people. Visual prostheses should be able to overcome this issue. Performance of mobility tasks involves at the same time a field of vision wide enough (detection of potential obstacles) and acuity (identification of visual cues). With the current visual prostheses, only a narrow field of vision can be transmitted at once. Information about the whole surrounding scene is retrieved by a scan of the head, which is a long and tedious task. Our study aims to improve the effectiveness of image treatment prior to stimulation with two proposals: first, we propose to take into account gaze direction by integrating an eye tracking system, as eye movements are known to participate to the construction of spatial relationships between a subject and his environment. Secondly, camera image is processed in a non uniform way, according to a bio-inspired method of center/peripheral decomposition. This is intended to enlarge field of view provided by prosthesis. We present the results of preliminary tests conducted on sighted people equipped with a prosthetic vision simulator based on a virtual reality device.

The use of eye movements to study and improve driver safety

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Our laboratory has been examining eye movements while people drive cars, both in a driving simulator and on the road, in order: a) to understand the increased crash rates for both novice and elderly drivers and b) to help develop training programs that take under an hour to complete to remediate these problems. A major cause of accidents for novice drivers was hypothesized to be a failure to anticipate unseen hazards. Using an eye tracker, we have observed large differences between novice and experienced drivers that are largely remediated by our RAPT training program. A similar problem occurs for elderly drivers, but is mostly restricted to intersections. We have developed a somewhat different program for elderly drivers that eliminates their deficiency in monitoring regions where unseen hazards may emerge from. Another major cause of accidents among novice drivers was hypothesized to be a failure to monitor the roadway ahead of them. Again, using an eye tracker, we have observed such changes and, as above, we have developed a training program that remediates this deficiency. More generally, our research indicates that a significant part of the problems with these populations is not in brain "hardware" but in "software".

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Reading: Visual & Oculomotor Processes

Interword spacing and landing position effects during Chinese reading in children and adults

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We examined the effect of interword spacing on children and adults' eye movement behavior when reading spaced and unspaced Chinese text. Participants read single sentences in normal unspaced format, and word spaced format, and we examined saccadic targeting to all the two character words under both visual formats. Interword spacing facilitated word identification in both children and adults, and substantially reduced the time children spent refixating words relative to adults. Word spacing effects occurred to a similar degree for both children and adults with differential landing position effects for single and multiple fixation situations. For single fixations, there were clear preferred viewing location effects, whereas for multiple fixation situations landing positions were closer to word beginnings, and further into the word for adults than children. Furthermore, adults targeted refixations contingent on initial landing positions to a greater degree than did children. Overall, these results indicate similar levels of maturity in children and adults for some psychological processes associated with reading (e.g., saccadic targeting between words), whilst other aspects suggest differing levels of maturity (e.g., linguistic processing).

Is there a vertical component to saccade targeting in Chinese reading?

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Much evidence exists that low-level visual variables rather than high-level linguistic variables affect initial landing positions in reading of alphabetic language scripts [Rayner, 2009, *Quarterly Journal of Experimental Psychology*, 62, 1457-1506]. Unlike alphabetic writing systems, written Chinese is logographic, with all Chinese characters occupying a square unit of space, but differing in their visual structure. We examined whether Chinese character structure influenced readers' saccade targeting in Chinese reading. Readers' eye movements were recorded when they read single sentences containing 1- or 2-character target words. Both 1-character words and the two constituent characters of the 2-character words had symmetrical left-right or top-bottom structure. The results showed that Chinese readers targeted their initial saccades to the word centre in single fixation cases and to the word beginning in multiple fixation cases, which replicated the previous studies [e.g., Yan et al., 2010, *Quarterly Journal of Experimental Psychology*, 63, 705-725]. However, the landing positions were very similar when readers initially fixated the target words with left-right and top-bottom structure. We conclude that Chinese character structure had little influence on initial landing positions during Chinese reading.

Word length and morpheme modulate saccade-target selection in right to left Uighur reading

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While there has been much research examining eye movements in scripts which are written from left to right, there has been little research into scripts which are written from right to left. Previous studies on Hebrew show that the preferred viewing location for Hebrew readers was to the right of the centre of words and that it was not modulated by inflectional morphological constraints. Here we report a study exploring the eye movement in Uighur script which is written from right to left with lots of suffixes. 28 Uighur undergraduate students, each of whom viewed single-line experimental sentences in Uighur script, participated in the experiment. The results demonstrated that the preferred viewing location for Uighur readers was to the right of the centre of words but covaried with the word length and proportion of suffix, which suggests that the morpheme plays a more important role in Uighur and that the readers begin to analyze information of the morpheme in the parafovea.

Do readers have preferred viewing locations in Chinese words when reading texts?

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The Chinese writing system has no empty space or boundary between words. This means that there is no perceptual cue for readers to decide where the next word is. So far, it is unclear if readers have preferred viewing location (PVL) in Chinese words. In this study, participants were asked to read Chinese physics texts which contained common words and unfamiliar physics words. Their eye movements were recorded. The results showed that, for the analysis of unfamiliar physics words, readers had no PVL in two-character words, but readers preferred sending their eyes to the first and the second character when reading three- and four-character words. For the analysis of common words, readers preferred fixating the first character ($M=46.42\%$) rather than the second character ($M=39.97\%$) of a two-character word. With regard to common three-character words and four-character words, readers had similar PVL as with reading unfamiliar physics words.

Where dyslexics look first in a stimulus: The influence of visual and linguistic factors on saccade computation

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In addition to appropriate phonological abilities, learning to read requires an accurate visual analysis that allows for precise decoding of the written words. The present study examines the possibility that a disturbance in the early processing of visuo-perceptual information needed to guide eye movements may be an important factor in dyslexia. We assessed the eye movements of three groups of children: dyslexic readers, unimpaired reading-level controls (RL-controls), and unimpaired chronological-age controls (CA-controls). Participants were asked to perform a lexical-decision task on stimuli presented either left or right of an initial fixation point. The most important result of this experiment was a saccade-size asymmetry between left and right presentations for all three groups of participants, although the asymmetry obtained for the dyslexics and RL-controls was less pronounced than for the CA-controls. The dyslexic readers did not differ from the RL-controls on gaze duration or lexical-decision time, and both of these groups exhibited sensitivity to word frequency and lexicality. The only substantial difference between the dyslexics and the others occurred when they had to process pseudowords in the right visual field, where their gaze duration, lexical-decision time, and second-saccade landing position deviated markedly. The theoretical consequences of these results are discussed.

The manipulation of saliency of parafoveal stimuli as a means for studying preview effects

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The present study used a variant of the incremental priming technique for examining the effects of valid versus invalid parafoveal previews on word recognition. The incremental priming technique was originally developed by Jacobs et al. [1995, *Perception & Psychophysics*, 57 (8), 1101-10] with the objective of making possible a reliable estimation of priming effects by means of varying the saliency of the primes. The present modification of the technique consisted of manipulating the saliency of valid and invalid parafoveal previews (e.g., preview: Tkcnv; target: Alarm). The manipulation was realized by removing different amounts of black pixels from the bitmap of the parafoveal stimulus. As expected, naming latencies increased when the saliency of valid previews decreased. On the contrary, naming latencies decreased with decreasing saliency of invalid previews. This pattern of findings allowed an estimation of facilitatory and interfering effects of valid versus invalid parafoveal previews on word recognition. An important implication of the study is that the modification of the incremental priming technique seems to be a convenient method for studying preview effects on visual word recognition in eye movement studies in reading.

The effect of spacing on preview effects for one-character and two-character words in Chinese reading

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Using the boundary technique, we examined the influence of adding spaces between words on preview effects during Chinese reading. Besides the preview of a character (identical or pseudo-character), two further manipulations were implemented: (a) the target word was one-character or two-characters in length and (b) the sentence was either unspaced, or spaced with the boundary location before or after the blank space preceding the target word. We observed shorter fixation durations on the target words in the spaced versus unspaced conditions consistent with the results obtained by Bai et al. [2008, *Journal of Experimental Psychology: Human Perception and Performance*, 34(5), 1277-1287]. More importantly, we found a larger preview effect in the word spaced condition compared to the unspaced condition for one-character, but not two-character targets. The lack of effect for the two-character words was likely caused by subjects mis-segmenting the target in the unspaced condition. In all likelihood, the larger preview effect for one-character targets in spaced compared to unspaced text occurs due to a combination of reduced lateral masking and a veridical cue to the short length of the word. Overall, our results indicate that spacing facilitates reading at a local level, and that word length modulates facilitatory spacing effects in parafoveal processing during Chinese reading.

Reading: Phonology & Speech

Eye tracking indicators of miscues in EFL readers

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This study aimed to investigate the relationship between seven eye-movement indicators and miscues in beginning EFL students in Taiwan. The term "miscue" [Goodman & Marek, 1996, pp.39-47] describes an observed response in the oral reading process that does not match the expected response. Goodman uses the term "miscue", rather than "error" or "mistake" to avoid value implications. In this study, the miscues were identified by misreading analysis technique while the eye movement indicators [Paulson & Goodman, 1999, Southern Arizona Review, 1, 55-62.] include first fixation duration, first gaze duration, first gaze fixation count, rereading time, regression rate, total fixation duration, and total fixation count. The participants were 13 8th-graders students with above average reading proficiency in English compared to their peers. All participants were asked to read aloud an English expository article. Video and eye movement data were collected during the experiment and the data were analyzed with ANCOVA and regression. The results firstly indicated that first fixation duration (FFD) increased for long words. Although there was no significant relation between FFD and misreading, six other indicators were strongly related to all forms of miscues. In sum, oral errors in reading require intensive cognitive processing including attention, semantic processes, and syntactic processes.

The role of phonological activation in Chinese reading

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This study investigated the role of phonological activation in Chinese reading comprehension. Two eye-tracking experiments, in which articulatory suppression and concurrent listening interfered with subjects' reading processes, were conducted to examine this issue. In Experiment 1, thirty native Chinese speakers were asked to read and comprehend twenty short Chinese expository texts under five conditions: articulatory suppression, reading aloud, reading while listening to irrelevant speech, reading while listening to the same text, and silent reading. The results showed that reading conditions did not exert an effect on comprehension scores, but had significant effects on subjects' eye-movement behavior. Greater saccade length and higher regression rate were especially found in the condition of articulatory suppression. Experiment 2 further examined whether subjects with background knowledge relevant to text content depended less on phonological activation in the process of reading comprehension and vice versa. The results indicated that articulatory suppression had a negative effect on reading comprehension. Subjects with background knowledge performed better on comprehension tests, regardless of reading conditions. Significant effects on eye movements were found in reading conditions, but not with background knowledge. The role of phonological activation in reading will be discussed in line with subjects' eye-movement behavior.

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High working memory performers have an efficient eye movement control system during reading

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Verbal working memory designates a system involved in the temporal storage and processing of information and it supports higher cognitive functions such as language comprehension during reading. Executive functions have drawn special attention, because they serve as visual attention controllers that allocate and coordinate attentional resources for reading tasks [Engle et al., 1999, *Journal of Experimental Psychology*, 128, 309-331]. Allocation and coordination of visual attention by the executive system can be analyzed using eye movements. We assumed that high working memory performers would be more efficient in focusing attention on target word in the text, due to efficient eye movement control than low-performers. Thirty-one undergraduate students were divided into high and low working memory score groups using the Reading Span Test [RST: Osaka, 2011, Open University DVD(DSE141), The Open University, UK]. The top nine (average score 4.1) and bottom nine (average score 2.7) students were asked to perform the RST, while their eyes were tracked (Tobii T120 system). We found that fixation durations on the target word were longer for high working memory students than for low working memory students, while significant intrusion errors were found in low working memory students. These results strongly suggest that students with high working memory capacity can efficiently focus attention on the specified word within a text, and thus are efficient at reading texts.

Children's eye movements when reading rotated text: The importance of digraphs

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Digraphs are pairs of letters in words that combine to make one phoneme. We examined whether children represent digraphs in the lexical identification system. We measured eye movements as they read sentences containing a target word in one of four conditions: 1) no-rotation, 2) digraph rotated congruently (where both letters were rotated in the same direction, but in the opposite direction to the rest of the letters of the word) 3) digraph rotated incongruently (each letter of the digraph was rotated in opposite directions) or 4) random rotation across the whole word. Preliminary analyses showed a consistent effect of rotation congruency such that reading times for the congruent and control conditions were not different, but were reliably shorter than for the incongruent and random conditions which themselves were not different. This effect occurred for first fixation duration, gaze duration and total time on the target word. This suggests that digraphs are represented in the word identification system and are important during lexical access.

Reading: Sentence & Text Processes

Number interference in sentence processing

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According to interference models [Lewis & Vasishth, 2005, *Cognitive Science*, 29, 375-419; Van Dyke & Lewis, 2003, *Journal of Memory & Language*, 49, 285-316], object-relatives (1) are harder than subject-relatives (2) due to interference when the noun phrases (guitarist and pianist) are integrated with the verb. Interference should be larger for object-relatives with similar noun phrases. We tested this in two eye-tracking experiments contrasting object- and subject-relative clauses with noun phrases that are the same or different in number: 1/ "The guitarist(s) that the pianist(s) frighten(s) seemed to be hungry and very tired.", 2/ "The guitarist(s) that frighten(s) the pianist(s) seemed to be hungry and very tired.". While Experiment 1 confirmed that object-relative clauses were harder, number congruency did not affect difficulty. One reason might be that number congruency is an integrative effect that occurs following the relative clause, and was spread out across the words following it. Using a shorter final region (seemed to be hungry) Experiment 2 showed that number congruency increased the difficulty of object-relatives in the final region, but not in the relative clause region. In conclusion, the effect of number interference is weak and occurs later than the relative clause effect. These results suggest that initial difficulty with object-relatives is not due to memory interference.

Native-language influence in foreign-language syntactic processing? An eye-tracking study

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Current accounts of foreign-language syntactic processing [e.g. Clahsen & Felser, 2006, *Applied Psycholinguistics*, 27, 3-42; MacWhinney, 1997, In de Groot & Kroll (Eds.), pp. 113-142] differ regarding the role of the native language. In an eye-tracking experiment, we investigated whether non-native speakers activate syntactic information from the native language (L1) while reading foreign-language (L2) sentences. Native speakers of German and English read English sentences such as (1): (1a) "David baked the rolls during the break" (grammatical in English and German) (1b) "David baked during the break the rolls" (ungrammatical in English, but grammatical in German) (1c) "David during the break baked the rolls" (ungrammatical in English and German). If L2 readers activate L1 syntax, Germans should find (1b) easier to process than (1c). At the prepositional phrase, results for both subject groups showed significant effects of condition for first-pass reading times, regression-path times, regressions, and total times, with (1a) being easier to process than (1b) and (1c), and with (1c) being easier to process than (1b). However, we found no differences between the German and English groups. We conclude that the L2 speakers did not activate L1 syntax, but dealt with the ungrammatical structures in a similar way as the native speakers.

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Combining eye-movement and key-logging data in written sentence production

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In this talk we present a reanalysis of results from a study published lately [Nottbusch, 2010, *Reading & Writing*, 23, 777-801]. In this study participants were asked to describe pictured events in a type-written sentence, containing one of two different syntactic structures (subordinated vs. coordinated subject noun phrases). According to the hypothesis, the larger subordinated structure (one noun phrase including a second, subordinated phrase) should be cognitively more costly and should be planned before the start of the production, whereas the coordinated structure, consisting of two syntactically equal noun phrases, could be planned locally in an incremental fashion. The hypothesis was confirmed by the analysis of the word-initial keystroke latencies as well as the eye-movements towards the stimulus, indicating a stronger tendency to incremental planning in case of the coordinated structure. Although keystroke and eye-movement data were analysed in parallel but in separate statistical tests, i.e. the fixations on the areas of interest were analysed with respect to the word that was concurrently written. For the reanalysis we tried to find a way to combine both measurements in mixed models. The comparison of the results will be accompanied by a discussion of the theoretical and practical implications of this approach.

Virtual grammaticality - Grammatical illusions

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Grammatical illusions in language processing are the linguistic equivalent of optical illusions in visual processing. A grammatical illusion amounts to an expression that is judged acceptable in spite of its grammatical deviance. It is the hitherto unnoticed fourth 'aggregate state', that completes the set of four logical pairings of the properties '(un-)grammatical' and '(un-)acceptable'. A typical source of syntactic illusions is the processor's attempt to repair grammatical inconsistencies, resulting from contradicting requirements of syntactic regularities. The pseudo-solutions tend to be judged as acceptable, although they patently remain ungrammatical. A consequence of the existence of this phenomenon is evident: acceptability is neither a sufficient nor correlate of grammaticality. Acceptability is neither a necessary nor a sufficient property of a grammatical construction. The attempt to model any construction that is (introspectively) judged as grammatically well-formed is tantamount to the attempt to devise a grammatical derivation for an ungrammatical construction. Consequently, it is bound to get overly complicated and to over-generate or crash. The eye movement protocols of 30 subjects show how speakers process grammatical illusions and what effects such illusions have on eye movements during reading.

The effects of WMC and epistemological beliefs on the use of headings and topic sentences to comprehend a text

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Previous studies indicated that reading headings and topic sentences is a strategy used by good readers. Readers with low working memory capacity (WMC) do not use the strategy often, but the effect can be offset if the readers have mature Epistemological Beliefs (EB). The purpose of this study is to use eye tracking techniques to reveal how readers of different WMC and EB use headings and topic sentences to read a text. Fifty nine college students serve as participants. Their eye movement patterns were recorded by an eye tracker while they were reading a text. The results found that the duration of the first-pass progressive fixation, first-pass rereading fixation, and look-back fixation on headings were longer than on topic sentences and other sentences and that the look-back time spent on topic sentences was longer than on other sentences. Also, low WMC subjects looked back longer than high WMC subjects and they had poorer literal comprehension. The expected interaction effect of EB and WMC was not found. These findings suggest that the readers relied on headings to integrate meanings, low WMC readers used look back to compensate their smaller WMC, and EB did not offset the WMC effect.

Eye movements when integrating scientific text and graphic information: The effect of sequential layouts on graphics

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The purpose of this study was to investigate the cognitive process of integrating scientific text and graphic information by monitoring readers' eye movements. Half of the participants read the scientific text containing an interpretational graph with sequential arrows indicating the corresponding concept in the text. The other half of participants read the same text but without sequential arrows in the graph. After reading the scientific text, participants had to do a reading comprehension test which had three types of questions: textual, sequential and integrative. The results showed that readers who read the sequential-arrow text tended to spend more time and made more fixations while reading the graphic part than those readers who read non-sequential-arrow text. The former also had shorter mean saccade length in the graphic part than the later. In addition, readers who read the sequential-arrow text also had a higher percentage of correct responses on the sequential and integrative reading comprehension questions. The above findings indicated that when the graphic provided sequential information, readers tried to use this resource and guide their attention to more accurate locations in order to integrate the information from the text and the graphic and form a better conceptual representation.

The effect of sound intensity on cognitive processing

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Sound is omnipresent in everyday life. Music and talkshows often accompany us to work and school. Background noise is present when relaxing in a park by reading a book or studying at a café. However, research is equivocal, and there are conflicting results as to whether sound and noise are beneficial or detrimental to cognitive processing. A recent study showed that studying with any kind of sound stimuli decreased performance on a reading comprehension test [Johansson et al., 2011, *Psychology of Music*]. Furthermore, the study showed that participants did not adapt their reading behaviour to compensate for the effects of the sound stimuli. A fundamental question is how sound environment affects cognitive processing when reading a text. In the current study we examined how a specific sound characteristics such as intensity (dB) affected students reading behaviour and text comprehension. In the study, 40 participants read text in three sound conditions (nonsense noise 50 dB, nonsense noise 70 dB, silence). We measured their eye movements, stress levels as measured by Galvanic Skin Respons-GSR, and performance on a reading comprehension test. Initial results showed increased stress levels for higher intensity (70 dB) of the sound environment.

Investigating 'private' second language writing processes with complementary data collection methods

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"Writing is not necessarily something to be ashamed of, but do it in private and wash your hands afterwards" (Robert Heinlein, 1907-1988). Our increasing understanding of second language (L2) writing processes has begun to illuminate the enormous difficulties faced by foreign language students when they compose texts in English. The proposed research described in this presentation aims to investigate the complex cognitive activity underpinning the planning, formulation, transcription, reading and revising processes involved in the production of L2 academic texts by Japanese university students. In order to help learners with the problems they face, we need to have a clear idea of exactly what is happening, moment by moment, inside the writer's head, but tapping into these cognitive processes is far from easy. By combining complementary data collection methods (eye tracking, keystroke logging, stimulated retrospective think aloud (SRTA) protocols, and discourse analysis), we aim to provide a rich description of the real time L2 text construction and revision processes used by Japanese students at different levels of proficiency. This should enable us to develop training materials, based on sound empirical evidence, with which to raise learners' awareness of effective strategies for writing in a second language.

The locus of reformulation in sight translation: Evidence from eye movements

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While the three components of interpreting have been identified as comprehension, reformulation, and production, the question of how these components occur has remained relatively unexplored. Against this backdrop, the present study applied an eye-movement recording technique to investigate the moment-to-moment processes of sight translation, an important interpreting mode with written input and oral output. Eighteen interpreting students participated in the eye movement experiment and performed three tasks on six short Chinese passages: silent reading, reading aloud, and Chinese to English sight translation. The data of first fixation durations, gaze durations, fixation probabilities, and refixation probabilities showed a similar pattern for sight translation and silent reading, which differed from the pattern for reading aloud. These findings suggest that during word recognition, sight translation shares a similar process with silent reading while no additional efforts are needed. The process of sight translation also revealed the cost of reformulation in the information integration stage, as evidenced by higher rereading time and rereading rate than silent reading. Pedagogically, it is important for interpreting students to recognize such a cognitive process in sight translation so they can develop coping strategies in each stage and efficiently engage in deliberate practice to improve the quality of learning.

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Scenes: Saliency & Object Search

Human Sensory Model - A simulator to predict human gaze when receiving a banknote

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We aim modelling the exchange of a banknote (Perception, vol. 36, p.127, "Accepting banknotes: A mixture of visual perception, tactility, and trust"). We try to predict where the attention of the receiver of a banknote is attracted. We identified the iLab Neuromorphic Vision C++ Toolkit (<http://ilab.usc.edu/toolkit/overview.shtml>) developed and maintained by Laurent Itti at the University of South California as a potential tool that could help us in this respect. An evaluation by a MoS student confirmed that it is worth going to a thorough evaluation. The developed simulator - named Human Sensory Model (HSM) - will be demonstrated live. Two projects follow: 1) Validation of the predictions of the HSM by correlation with Eye Tracking (ET) experiments; there is a need to develop a methodology, to shape and to conduct the ET experiments, to correlate with HSM predictions and validate according to the agreed methodology, 2) Study potential synergy between tactile and visual information included in the banknotes: this is a first approach but the ultimate aim is to include the tactile information also in the HSM.

Jean-Claude Gilles, principal R&D expert at the European Central

The interaction of visual and linguistic salience in guiding eye movements

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The effect of visual salience on language processing has been studied in depth, but its interaction with linguistic salience is still poorly understood. We investigated this interaction by manipulating the visual salience and the linguistic salience of pictorial landmarks on a map. Forty participants received four instructions in a sequence guiding them from a starting point (e.g. a train station) to a final location (e.g. a castle). Visual salience was manipulated by modifying the size and colors of some of the pictures. Linguistic salience was manipulated via linguistic references related to the landmarks (e.g. the train station of the birthplace of the painter Depero; the castle where Depero's exhibition is). We found that linguistic and visual salience influenced gaze patterns in different ways. The duration of fixation on the first landmark showed a significant difference between linguistic and visual salience and an interaction between the two during the first instruction. In the last instruction, by contrast, the gaze duration on the target and competitor landmarks was significantly different only in the linguistic salience condition. In conclusion, visual salience had an influence during the first stage of the task while linguistic salience helped resolving linguistic ambiguities overcoming visual salience.

Features of ambient and focal fixations on natural visual scenes

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On the basis of the dichotomic processing of visual perception, literature has suggested two kinds of eye fixations. Ambient fixations are characterized by global and fast scanning of the scene while focal fixations relate to finer analysis of localized regions. We propose an automatic method to discriminate ambient and focal fixations. From this classification, the features of the clustered fixations are examined. Firstly, we observed a different sensitivity to bottom-up saliency predicted by state-of-the-art saliency models (focal ones are more salient than ambient ones). Secondly, it was observed that the influence of the central bias is not the same for focal and ambient fixations (focal fixations are more concentrated on the screen's center). Thirdly, the occurrences of these fixations were time-dependent. Finally, we observed a link between ambient/focal processing and object presence. Our results indicated that 43 % of focal fixations were localized on objects and 57 % on a context (i.e. visual scene not including the objects) while only 73 % of ambient fixations were situated on a context. These different features of ambient versus focal fixations offer new perspectives in computational modelling of visual saliency.

Visual similarity effects in categorical search

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Do visual similarity relationships affect search guidance to categorically-defined targets? Experiment 1 used a web task to collect visual similarity rankings between two target categories, teddy bears and butterflies, and random-category objects, from which we created search displays in Experiment 2 having either high-similarity distractors, low-similarity distractors, or "mixed" displays with high, medium, and low-similarity distractors. Analysis of target absent trials revealed faster manual responses and fewer fixated distractors on low-similarity trials compared to high. For mixed displays, first fixations were more frequent on high-similarity than on low-similarity distractors. Experiment 3 used the same high/low/mixed conditions, but now these conditions were created using similarity estimates from a computer vision model that ranked objects by color, texture, and shape similarity. The same patterns were found, suggesting that categorical search can indeed be guided by purely visual similarity. Experiment 4 compared cases where the model and human rankings differed and when they agreed. We found that similarity effects were best predicted by cases where the two sets of rankings agreed, suggesting that both human visual similarity rankings and the computer vision model captured different features important for guiding search to categorical targets.

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Visual search in real-world scenes: The role of color during target template guidance

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A target template held in visual working memory facilitates search when it contains specific visual information. However, it is not fully understood which exact search behaviors individual features of a template facilitate. In the current study, we investigated which eye movement behaviors a target template's color facilitates while searching through real-world scenes. In two experiments, the search target was cued with word labels, word labels with a representative color swatch, grey-scale pictures, or full-color pictures of the target. Participants' eye movements were recorded, allowing search time to be segmented into three behaviorally defined epochs: search initiation time, scanning time and verification time. The results indicate that prior knowledge of a target's color facilitates the scanning and verification epochs. In particular, color appears to be of greatest importance to search when selecting the next saccade destination, indicating that color is a dominant feature used in weighting an activation map. However, though color information also facilitates verification, additional visual features are needed for the process to reach ceiling level. The results support recent target template search models and add to our understanding of real-world search.

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Color-based target preselection in real world visual search

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In contrast to most other mammals, some primates including humans have evolved trichromacy. The improved red-green discrimination may facilitate detection of ripe fruit and establish an evolutionary advantage. We test this hypothesis in a combined color and shape- search task performed by dichromat (colorblind) and trichromat (normal) humans in a natural setting. Berry-like candies, "Smarties" and "m&m's", were distributed evenly on a field (800 m², ~17000 Objects, 3% Smarties). Both types were present in six different colors and differed slightly in shape. The participants performed three tasks. (1) Search for Smarties of any color amongst the m&ms (distractors). (2) Searching exclusively for red Smarties induced a increase of fixations on red distractors from 18% to 45% in normals. Colorblinds still fixated only 11% of red distractors, suggesting that they couldn't narrow down the search to the target color, although they could distinguish it from the other colors when shown. (3) During search for yellow Smarties, both groups fixated the same proportion of yellow distractors (63%). In contrast to normals, colorblinds cannot improve their search performance by preselecting red targets; however, they still use color information along the yellow-blue axis for pre-selection of potential targets.

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Ultra-fast saccades to baby faces and adult faces: How early can we choose?

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When two photographs are presented in the left and right of visual fields, reliable saccades towards face targets can be initiated in as little as 100-110 ms [Crouzet et al, 2010, *Journal of Vision*, 10(4):16, 1-17]. To explore further this remarkable ability we performed experiments with two kinds of stimuli: adult and baby faces, on 16 subjects. When these targets are paired with highly varied and complex natural scenes as distractors, performance was remarkable, with an overall mean accuracy of 94% and an overall mean RT of 147.8 ms. Minimum Reaction Time (defined as the first bin with significantly more correct than false responses), was 102 ms for both adult and baby faces suggesting that both stimuli are equally effective at triggering fast saccades. In other experiments, baby faces were paired with adult faces, and subjects instructed to target one or other category. With baby faces as the target, a bias could be demonstrated from 132 ms, but when adult faces were the target, the bias only became visible from 148 ms. The results suggest that baby faces may be more effective as a target than adult faces, even though both stimuli are equally effective in triggering very fast saccades.

Females capture but don't hold each other's faces: An eye movement study

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The human face, due to its high social and biological significance captures and retains our attention; hence it is also better remembered when compared to other objects. Female faces are only better remembered by females, resulting in an Own-Gender Bias (having a better memory for faces of their own gender). Males however do not show such a bias. The mechanisms underlying Own-Gender Bias have not been fully understood. The present study examines whether there are differences in attentional capture and retention between male and female faces, and whether these differences are more prominent in males or females. A measure of reaction time and eye movement behaviour was taken during a visual search task where the face was not task relevant. Initial exploration of the results shows that while there is no influence on latencies, an initial orientation effect is present for females. The presence of a female face slowed down the females' attention (males' data is still being collected) towards the search target; however the male face did not have such effect. This initial orientation does not seem to last, indicating that females' attention tends to be only captured initially by the female face, and not held by it.

Objects & Words: Attention & Field Effects

Attentional bias of spatial location in viewing scenes: Evidence from eye tracking research

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Various asymmetries of visual fields have been observed when people perceiving visual stimuli [Dickinson & Intraub, 2009, *Attention, Perception, & Psychophysics*, 71 (6), 1251-1262]. There are two main types of visual-field asymmetries: right/left hemi-field asymmetries and upper/lower visual hemi-field asymmetries [Michael & Ojéda, 2005, *Neuroscience Letters*, 388, 65-70]. Considering that scenes differ from the other types of visual stimuli which have been chosen by previous papers in a number of important ways, it is still an open question whether there is an overall attentional bias of horizontal and vertical visual fields in viewing nature scenes. Participants freely viewed real-world pictures, while their eye movements were monitored with a Tobii T120 eye-tracker. The dependent variables were locations of the first fixation, as a measure of endogenous attentional bias before picture onset; Initial saccade direction, as a survey of the initial distribution of attention during observers' first fixations on pictures; and fixation duration, as a reflection of visual asymmetries during the whole process. Results revealed that there are leftward and upward attentional biases in viewing natural scenes. The present findings have implications for driving, aviation, advertisement and other fields where visual attention is important for safety and efficiency.

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Bilateral saccades reduce meaningfulness facilitation on recognition

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Recent studies have demonstrated that horizontal bilateral saccades enhance episodic memory retrieval. We examined whether this improvement could also be observed for mixed-format visual pairs, and when a part of information is meaningless. In an old-new recognition task, the pairs were formed by two meaningful items (object/word) or by a meaningful and a meaningless item (object/pseudoword or word/pseudo-object). After the study phase, participants engaged bilateral saccades or maintained fixation, for 30 sec. In the test phase, items were briefly (180 ms) presented to separate hemispheres, one in the left and one in the right visual field. Responses were slower and less accurate for pairs with a meaningless item than for object/word pairs, but this effect on RTs was only significant in the fixation condition. This suggests that saccades facilitate retrieval of a more veridical representation, reducing the need to activate semantics. Eye movements did not interact with visual field and, in particular, did not enhance performance when information was addressed to the functionally specialized hemisphere (the LH for verbal and the RH for non-verbal items). This raises some doubts about previous interpretations of the facilitation of bilateral saccades in terms of increased interhemispheric interaction or better intrahemispheric processing.

Eye movements during multiple object naming reflect the gating of information by attention

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Studies of multiple-object naming with gaze-contingent display changes suggest that objects are processed in parallel [Malpass & Meyer, 2010, *Journal of Experimental Psychology: Learning, Memory & Cognition*, 36, 523-537; Morgan & Meyer, 2005, *Journal of Experimental Psychology: Learning, Memory & Cognition*, 31, 428-442]. Given this simultaneous processing, we investigated how speakers are able to select the correct object to be named and ignore irrelevant distractor objects. In two experiments using a modified multiple object naming paradigm, subjects were required to name several objects in succession when previews appeared briefly and simultaneously in the same location as the target as well as another location. In Experiment 1, preview benefit—faster processing of the target when the preview was related compared to unrelated—was found for the preview in the target location but not a location that was never to be named. In Experiment 2, preview benefit was found if a related preview appeared in either the target location or the third-to-be-named location. These data suggest that attention serves to gate visual input about objects based on the intention to name them, and that information from one intended-to-be-named object can facilitate processing of an object in another location.

The attentional bias in lateralized word recognition: Evidence from saccadic studies

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The right visual field superiority defines the fact that words presented to the right visual field (RVF) are recognized more readily than those presented in the left visual field (LVF). The attentional bias theory proposed an explanation in terms of attentional imbalance caused by the selective activation of the left hemisphere with verbal tasks whereas the attentional advantage theory postulates that the left hemisphere may process verbal material by using less attention. Only one study examined the effect of orienting attention by saccade preparation on the RVF superiority [Hyönä and Koivisto, 2006, *Laterality*, 11(2), 155-169]. Compared to a fixation condition, the saccade preparation toward the stimulus improved performance only in the LVF, cancelling the RVF superiority. By using similar move and fixate conditions with young and old participants (Experiment 1), we found a RVF superiority in both conditions with only a small benefit from saccade. Performance of older people decreased for both visual fields. In Experiment 2, young subjects had to saccade to the same or to the opposite side of the word stimulus. For RVF presentation, the saccade preparation toward the opposite side decreased performance compared to the same side condition. These results argue for the attentional bias theory.

Congruency effects on memory recall and matching in audio-visual concentration games

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Surprisingly few studies explored Stroop-like congruency effects [Stoop, 1935, *Journal of Experimental Psychology*, 18, 643-662] outside the visual modality [Morgan & Brandt, 1989, *Brain and Language*, 36(4), 592-603]. We investigated how simultaneously displaying congruent or incongruent visual and auditory stimuli affects performance and attention in a memory recall and matching task. Participants played the concentration game ("memory"), matching pairs of images or sounds while either congruent or incongruent sounds or images were presented alongside. Results show increased response times and error rates for both image and sound matching tasks when incongruent auditory and visual stimuli, respectively, are co-presented, compared to the congruent display condition. Sound matching is more strongly affected by the simultaneous display of incongruent images than image matching while playing incongruent sounds. In the incongruent condition, more and longer fixations and saccades to locations that correspond to the incongruent co-stimulus are recorded. We conclude that Stroop-like congruency effects also exist for cross-modal stimulus presentations, with "distraction" from the auditory modality by visual co-stimulation being stronger than vice versa. Processing concurrent visual and auditory information is dominated by the visual input and cannot easily be ignored in auditory tasks. It affects visual processing patterns and impedes attention guidance.

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Dynamic Scenes

Watching you watch movies: Using eye tracking to inform film theory

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In 1916 the Psychologist Hugo Münsterberg predicted that film would "become more than any other art the domain of the psychologist" (1916: page 181). Münsterberg realised that empirical investigation was essential for understanding how we perceive edited sequences of film and the impact of compositional and stylistic decisions on viewer experience. Sadly, Münsterberg's call-to-arms was never taken up and still today we are left with only a rudimentary understanding of how we perceive film. Recently, there has been a re-emergence of interest in how empirical psychology can inform film theory. Eye tracking has great potential in this domain by indexing the on-line cognition of film viewers. In this presentation I will focus on two empirical case studies investigating eye movement behaviour during film viewing. First, I will discuss how viewer attention is choreographed in *There Will Be Blood*, (P.T. Anderson, 2007). Second, I will show how the recent rise in *Intensified Continuity* (Bordwell, 2006), a style of editing involving frequent close centrally composed shots has affected our perception of depicted scenes. The implications of this research for film theory and practice as well as our broader perception of naturalistic dynamic scenes will be discussed

Subtitle preference while viewing native language movies: The effects of subtitle familiarity and sound

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Subtitles are transferred from dialogues in the videos and help viewers process the content of movies and television. Preference or need for subtitles was found in studies of text and graphics integration and television viewing. In this study, the effects of subtitle familiarity and sound overlap on subtitle preference while viewing native language movies were investigated. In experiment 1, a movie clip was constructed with four types of subtitles, Chinese, English, random letters and blank, as stimuli materials. Results showed that the movie with Chinese subtitles was fixated more and longer than the movie with random letters and blank. Although the movie was in the local language and easy to process and understand, participants preferred to pay much attention to subtitles. For the subtitle processing, fixations declined from Chinese, English, random letters to blank subtitles. Subtitle preference was influenced by subtitle familiarity. Experiment 2 chose Chinese and English subtitled movie clips as materials, half of them with sound and the other half without sound. It was found that participants fixated more on the subtitle area than in the video when the sound was turned off. Number of fixations and fixation durations on subtitles of movies without sound were significantly higher than in movies with sound.

Processing of subtitles in foreign language films: An eye-tracking study

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Many European countries use subtitles to broadcast foreign language films and TV programs as a cheaper alternative to dubbing. Furthermore, native language films and TV programs are often offered optionally with different language subtitles. An important question is to what extent people process the subtitles. In this study, monolingual English participants unfamiliar with Dutch watched 25 minutes of a film under normal (Dutch soundtrack and English subtitles), reversed (English soundtrack and Dutch subtitles) or intralingual (Dutch soundtrack and Dutch subtitles) subtitling conditions whilst their eye-movements were recorded. The results revealed that the participants read the subtitles irrespective of whether they were presented in English or Dutch as assessed by the duration and the number of fixations in each subtitle. However, participants exhibited more regular reading of the subtitles when the film soundtrack was in Dutch. Furthermore, there were no significant differences between the normal and intralingual conditions, even in terms of consecutive fixations on the subtitles. The implications of these results are discussed in relation to the dynamic nature of subtitles and the highly automatic reading of words.

Audio cues for selective visual attention

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Audio description (AD) has become a cultural revolution for blind and visually impaired audiences, however the range of AD beneficiaries can be much broader. We claim that AD is a useful invention to effectively guide children's attention during the acquisition of new information. The paper presents results from an eye-tracking study. Forty four 8-9 year old children watched 2 clips from educational animation series for children "Il était une fois... la vie" while their eye movements were recorded. They were randomly assigned to two groups, either with or without audio description. We concentrated on testing the usefulness of AD in selective attention to described elements of the clip scene. Time to first fixation on AD objects, fixations durations and fixation counts served as primary dependent variables. The results confirmed that AD guides children's attention towards described objects resulting e.g. in more fixations on specific regions of interest. We postulate that audio description could complement regular teaching tools for guiding children's attention, especially when new concepts are being introduced. This would be especially applicable for children with short attention span who easily get distracted by task irrelevant information, for them AD could play the role of an external cue for their attention allocation.

Oculomotor consequences of disruptions to visual and narrative continuity in movies

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Movies play an important role in contemporary society, yet current understanding of how moving images are processed and in particular the perceptual consequence of editorial cuts on eye movement control is under-developed. We examined the oculomotor consequences of disruptions to visual and narrative continuity in movies by manipulating the camera angle and the position of the actors across an editorial cut. 180-degree camera angle change produces two types of visual discontinuities (changes to the left-right relationship of the actors on the foreground and the background content), while changing the relative position of the actors across a cut produces narrative discontinuity. The results suggested that disruption to both visual and narrative continuity affected inspection behaviour, but the time course of these effects varied across different parts of the scene. Immediately following a cut eye movements were influenced by the visual continuity of the film. However, over time, the consistency of both visual and narrative information affected where and for how long viewers looked in the scene. When watching movies the integration of visual changes into representations appears to take place quickly, but the influence of semantic changes in the updating of representations seems to happen over a longer time period.

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Visual correlates of fixation durations during scene transition

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When watching movies, our fixations are often interrupted by scene transitions, where one scene replaces the previous scene. When that happens, one may expect the visual system to abort the current fixation, and make a saccade to a new fixation location. However, when we performed eye-tracking experiments on subjects viewing movies, we found that fixation durations during transitions, when compared to those before transitions, were lengthened instead of being shortened (1-tailed Kolmogorov-Smirnoff test, $p < 0.01$). In addition, we found that fixations that ended within 220 ms of a transition were followed by fixations with durations that were shorter than those preceding the transition ($p < 0.01$). We also found significant differences in the average local contrast for early-terminating fixations compared to late-ending fixations ($p < 0.01$). However, the local contrasts for these late-ending fixations were still lower than those before or after the transition ($p < 0.01$). These results suggest that despite the large changes in a scene transition, the visual system analyzes the local information in the new scene, and if the contrast at the new location was sufficiently high, appears to be happy to continue the fixation rather than picking a new location.

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Scenes & Emotions

Combining information loading with the physical complexity of stimuli and the strength of emotion

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The present study aims at exploring the information load in viewing affective scenes by monitoring eye movement patterns. The present study used 100 pictures from the International Affective Picture System (IAPS, 2005) as stimuli. The pictures include 80 negative and 20 neutral ones, and both categories can be further grouped by content into 5 categories. The participants were asked to view the pictures twice, the first time with free viewing. The participants were given instructions for regulating their emotion before the second viewing. After the second viewing they were asked to rate the valence, arousal and information load. The subject rating data showed that there was a positive correlation between the arousal rating and the information-load rating (both with neutral and negative pictures, and with different contents) and between the number of viewing locations and the information load, especially in the second viewing of the negative pictures. However, there was less correlation between arousal rating and the number of viewing locations. This result suggested that the information load(mentally) was related not only to the complexity of the scene but also to the strength of feelings.

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Analysis of emotional picture viewing through eye movement recording

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When a neutral picture is paired with an emotional picture, subjects' eye movements are affected by the emotional one. In general, emotional pictures are more likely to attract first fixations than neutral pictures when both are presented simultaneously. In order to further investigate emotional picture viewing, the aim of this study is to analyze subjects' exploratory behaviour during the vision of emotional stimuli, by considering to what extent the thematic content (animate vs. inanimate) and the valence rating are likely to influence the observer's eye movements. Pictures have been selected as: neutral, pleasant, unpleasant. Two categories of thematic content have been created: animate (animals) and inanimate (objects, landscapes). 36 slides were created by coupling pictures within the possible combinations of thematic content and valence in a balanced way. The two pictures within a slide were paired horizontally. Gaze exploratory behaviour has been analysed in terms of static parameters (number of fixations, fixation duration, total permanence time) and dynamic strategies (first fixation location at the appearance of a new slide, number of transitions between pictures). Results show that subjects' behaviour viewing animate pictures is not affected by their valence, whereas viewing inanimate pictures is strongly related to valence rating.

Effects of mood induction on eye movements during dual scene inspection

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Recent studies indicate that individuals in a negative mood state are characterized by a cognitive bias for negative emotional information. Frequently, negative information has been contrasted with neutral information during simultaneous presentation of picture pairs. The current experiment examined whether this bias for negative information can also be found for negative-positive contrasts. After a mood induction procedure in which participants wrote either a negative or a positive event pertaining to their own life history, they freely inspected a series of picture pairs (i.e., negative-neutral; negative-positive). Results showed that negative mood induction led to a higher bias in initial orienting and maintaining of gaze on negative pictures than positive induction, during inspection of negative-neutral picture pairs. There was no difference between the two groups for eye movement measures in negative-positive picture pairs. Results are consistent with the hypothesis of a cognitive bias for negative stimuli in dysphoria, but only when negative stimuli are paired with neutral stimuli. In conclusion, much care should be taken in the process of interpreting existing data only contrasting negative-versus-neutral stimulation. In these studies, some variance could be explained by a cognitive bias for emotional information in general rather than only for negative information.

Eye movements and brain oscillatory responses during serial and free viewing of emotional images

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Co-registration of eye movements and the electroencephalogram (EEG) were used to assess the processing of emotional images. Previous studies have shown that 4 - 6 Hz brain oscillatory responses emerge as a response to serially presented emotional images. We recorded eye movements and the EEG simultaneously while 11 participants viewed images with varying emotional valence. Sets of four images were presented either serially or in parallel. An 'emotional' set included one image with a high positive or negative valence content among neutral images. A 'neutral' set comprised four neutral images. The participants were asked to indicate which picture - if any - was emotional and to rate that image on the valence and arousal dimensions. In the parallel (free viewing) condition, the EEG responses were analyzed time-locked to the first gaze on an image. In both presentation conditions, the results showed enhanced 4 - 6 Hz brain oscillatory responses at ~500 ms from image onset or from the first gaze on a negative image compared to the presentation of a neutral image. The results indicate that brain oscillatory responses can be analyzed time-locked to eye movements, and that similar responses emerge during serial and free viewing when the emotional stimulus was attended.

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Perception, Attention & Memory

Detection of orientation change during smooth pursuit eye movement

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Smooth pursuit eye movements stabilize the retinal image of small moving targets. Previous studies have shown that pursuit eye movement uses more attentional resources at the start and end of pursuit than during pursuit maintenance [e.g., van Donkelaar & Drew, 2002, In Hyönä et al. (Ed.), pp.267- 77]. In this study, we investigate whether detection of orientation change depends on the duration of smooth pursuit eye movement. Participants were asked to visually pursue a moving target and to press a key when the target pattern changed. The target was moved in a straight line (eight directions) at a constant velocity (5, 10, 15 deg/s) within a fixed distance of 20 deg. Eye movements were monitored by EOG. We compared five change-position conditions: 0, 5, 10, 15, 20 deg marks after the target began to move. We measured the reaction time of change detection and the perceived position at which a target changed. As a result, in all direction and velocity conditions, the reaction time was faster at 10-20 deg marks than at 0, 5 deg marks, while the error of position was the largest at the 10 deg mark. Finally, we discuss the relationship between visuo-motor control and attentional resources.

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Anisotropies of smooth pursuit gain and perceptual coherence sensitivity

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We investigated sensory and motor contributions to motion anisotropies. We presented three different types of random-dot kinematograms at three different coherences (20, 60, 100%), moving in four cardinal and four oblique directions. The three kinematogram types, transparent motion, white noise motion and Brownian motion differed in the noise computation [Schütz et al, 2010, *Journal of Vision*,10(13):26, 1-22]. Anisotropies of pursuit gain were more pronounced for low coherences, but were still present at 100% coherence. We found an advantage of horizontal over vertical directions, but no advantage of cardinal over diagonal directions. Pursuit gain tended to be higher for upward than for downward motion and higher for leftward than for rightward motion. Perceptually, strong anisotropies of motion coherence sensitivity were only present for transparent motion. Sensitivity was higher for horizontal than for vertical motion and for cardinal than for diagonal directions. As a result, perceptual coherence sensitivity was highly correlated with pursuit gain for transparent motion, but not for white and Brownian motion. This indicates that anisotropies can arise from sensory and motor sources. The anisotropies in transparent motion probably result from a sensory source whereas the ones in white and Brownian motion presumably stem from a motor source.

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Perception of stereograms is accompanied by vergent eye movements

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It is well known that I.M.Sechenov (1878), L.E.Javal (1896) and other researchers considered that people need vergent eye movements for perception of 3D objects and visual scenes in space. We conducted research of binocular eye movements of ten persons with normal binocular vision observing stereograms with horizontal parallax from 0.5 till 1.8 angle degrees. The observers saw these stereograms for the first time. Binocular eye movements were registered from the beginning of the stereogram observation till the moment of a steady stereo image perception. The binocular eye movements were registered by an HD video camera and computer programs for processing eye-movement video recordings (authors: D.A.Usanov et al, 2002, Saratov University). During the experiment the vergent eye movements of all participants were registered, while they were observing the stereograms. Vergent eye movements were detected before the moment of the stereo image perception. Vergent eye movements were detected as well as the process of observation of the seen stereo image and its' details. The research results indicated that vergent eye movements always accompanied the perception of stereograms with disparity from 0.5 till 1.8 angle degrees.

Influence of covert on overt attention shifts

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The current study seeks to understand the link between visual selective attention and eye movements. We try to unveil whether covert selection of one visual stimulus or location shares mechanisms with the programming of landing positions for a saccade [Rizzolatti et al., 1994, In Umiltà & Moscovitch (Eds.), pp. 231-265] or whether they are independent from one another [Posner, 1980, Quarterly Journal of Experimental Psychology, 32(1), 3-25]. In a first study we tested how eye movements are influenced by a preceding covert attention shift to same or different positions. Participants were first presented with an exogenous cue on one of four possible parafoveal positions and after a variable time interval with a screen indicating a different or the same position, to which a saccade had to be executed. Covert attention shifts produce costs for successive eye movements to the same relative to different positions. This effect is independent of the stimulus onset asynchrony (SOA). This contradicts findings about the timing of inhibition of return [Posner & Cohen, 1984, In Bouma & Bouwhuis (Eds.), pp. 531-556]. Possible explanations for this early inhibition effect and implications for the question of shared and independent mechanisms for covert and overt attention shifts will be discussed.

Covert attention shifts delay overt attention shifts

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In our study we investigated the impact of preceding covert attention shifts on following saccades. Covert orienting of attention could be either independent from the programming of a saccade [Posner, 1980, *Quarterly Journal of Experimental Psychology*, 32(1), 3-25] or it could be virtually the same process than a saccade [Rizzolatti et al., 1987, *Neuropsychologia* 25: 31-40]. We used a Posner cueing paradigm and measured the saccade latencies towards precued or away from precued locations. Covert attention shifts were measured with an electroencephalogram. We found that a valid precue delays the onset of a saccade and also inhibits early directed attention negativity in the electroencephalogram. Possible explanations for shared or independent mechanisms of covert and overt attention shifts will be discussed.

Saccade programming in the attentional double-step task

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In most everyday situations attention and saccades are coupled. Although attention obligatory precedes saccades, it is assumed that not every shift of attention is followed by a saccade. To examine conditions under which saccades follow attention we designed the attentional double-step task. Participants were cued to and had to attend to a big arrow in the periphery, which pointed to a small target letter. The task was to identify the target letter and no instruction was given regarding eye movements. Participants did not have to make a saccade to the arrow since it could be identified from fixation, but the target was too small to be identified without a saccade. The results showed that saccades generally first went to the arrow, but after a short fixation (130 ms) went on to the target location, suggesting that attention was shifted to the target location very shortly after the eyes arrived to the arrow. On about 15% of trials saccades went straight to the target, suggesting that attention was already at the target location by the time of saccade execution. We propose that if attentional dwell time is too short, shift of attention is not followed by a saccade.

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Attention-for-perception after a saccade: Evidence for the prioritization of the intended landing position in the fovea

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Before an eye movement is executed visual attention is allocated to the intended goal location of the impending saccade [e.g. Deubel & Schneider, 1996, *Vision Research*, 36, 1827-1837]. We deliver evidence for postsaccadic attentional enhancement at an intended saccade goal location. In the current experiment subjects had to saccade to the center of a string of five objects. After landing of the eyes a discrimination target (DT) was briefly presented at the goal location of the saccade or at one of two adjacent locations. Perceptual performance in a two-alternative forced-choice task was best if the location of the DT coincided with the location of the instructed saccade target. Distance of the DT from the center of the fovea did not influence discrimination performance. In short, within the fovea, intended saccade landing determines perceptual performance while relative foveal location does not matter. The current results also suggest that spatial parameters for allocating attention presaccadically are maintained across saccades. Combined with an efference-copy signal of the eye movement this could allow fast and accurate postsaccadic visual-spatial selection despite deviations of the actual from the intended saccade landing position.

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Using eye movements to track attention to objects in working memory

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Recent studies demonstrated that eye movements can be used to identify the allocation of attention to internal representations in spatial working memory (WM). Here, we used concurrent saccade data to expand upon the widely reported reaction time switch cost effect in WM [e.g. Oberauer, 2002, *Journal of Experimental Psychology: Learning, Memory & Cognition*, 28(3), 411-421]. In line with previous literature, participants were faster to indicate completion of an update (mentally moving the location of an object) when operating on the same object on successive steps than when switching attention to another object, indicative of a single item focus of attention in WM. This reaction time cost for switching objects was reflected in the landing positions of first saccades; participants were more likely to saccade to locations corresponding to the target of an update on repeat than on switch trials, despite no visual information being present. With multi-level regression, we showed a close link between saccades and participants' responses, with longer first saccade latencies to the updated target location being associated with longer reaction times. Our findings demonstrate the utility of eye tracking to examine the allocation of attention to internal representations, and shed new light on the mechanisms underlying switch cost effects.

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Eye movement-based rehearsal of complex instructions

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Previous research showed that rehearsal of spatial locations improves spatial working memory [e.g. Awh & Jonides, 2001, *Trends in Cognitive Science*, 5(2), 119-126; Fischer, 2001, *Brain and Cognition*, 45, 143-154]. Using eye movement measures, this study investigates this effect during memorising and executing multiple instructions in an assembly task. In particular, we examined whether eye movements towards relevant objects after the presentation of sequential verbal instructions and before the execution predict their successful completion. Twelve participants were presented with between two and six instructions, each of the form "Move the [object] to [location]". This was followed by a 6 s retention interval, after which the instructions had to be executed on a monitor by manipulating objects in a numbered grid with a mouse. During the retention interval, participants re-fixated objects and locations that were mentioned in the instructions, thus rehearsing the forthcoming action sequence. This anticipatory behaviour was limited by working memory capacity. Furthermore, there was a strong correlation between fixating mentioned objects and locations on the one hand, and a correctly executed instruction on the other hand. These results indicate that eye movements during retention predict the successful execution of instructions and thus reflect the updating of working memory.

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Saccadic Adaptation

Adaptation of reactive and voluntary saccades in children: Differences in retention and extinction

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We examine whether saccadic adaptation occurs in children for reactive and voluntary saccades (RS and VS), known to be sustained by separate neural substrates. Nine adults (23-36 years old) and nine children (11-14 years old) participated. Horizontal 10° saccades were elicited by gap-0 ms and overlap-600 ms paradigms in separate sessions. During the adaptation phase, a classical systematic target step was used to elicit the shortening of saccade gains in response to a 2° intrasaccadic backward step. All participants showed a progressive saccade gain shortening of both saccades suggesting that cerebral structures involved in backward adaptation of both saccades are functional at 11 years old. Retention and extinction of saccadic adaptation were examined with two conditions ran in pre- and post-adaptation phases, without and with postsaccadic visual feedback respectively. In children, the retention of adaptation was good only for RS, suggesting that adaptive mechanisms sustaining the saccade gain shortening differ from those subserving retention and are not mature and functional at the same time. Finally, children showed slower extinction of the RS adaptation than adults, suggesting that saccade gain lengthening is not yet well established. We hypothesized that mechanisms responsible for backward adaptation mature before those for forward adaptation.

Efference copy and error signals in saccadic adaptation

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Systematic errors in targeting saccades can lead the oculomotor system to change its response to a visual stimulus within minutes. To achieve this remarkable adaptability, the oculomotor system must combine several sources of information. First, adaptation requires an error signal about the inappropriateness of previous targeting behavior. Second, it requires some knowledge about oculomotor variability, since small and even systematic errors can occur because of oculomotor noise and undershoot. We examined the relative contributions of these sources of information to adaptation, and hypothesized that each would be weighted according to its reliability (inversely related to variability). We furthermore examined whether their combination was compatible with a Bayesian framework. For large amplitudes, variability is high, thus the system would be more prone to adaptation. We manipulated the variability of the error signal by drawing the size of the intra-saccadic back-step from distributions of varying width in separate sessions. We hypothesized that the more variable the back-step, the less likely it was to evoke adaptation. Thus, greatest adaptation would occur for large saccades with a fixed back-step, and least adaptation would occur for small saccades with a variable back-step. Results suggest that these two parameters do play a role in saccadic adaptation.

Saccadic plasticity and posterior parietal cortex

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Exploring our visual environment requires saccadic eye movements. Saccade accuracy is maintained over the long-term despite changing conditions (e.g., growth, aging, lesions) by saccadic adaptation processes. Here, we present direct evidence for a role of the oculomotor area of the intra-parietal sulcus (IPS) in saccadic adaptation. First, a fMRI study delineated the brain network specifically related to saccadic adaptation induced in a target double-step paradigm. The timing of the backstep target was manipulated to yield a systematic visual error either 50 ms (adaptation paradigm) or 500 ms (reference paradigm) after saccade termination. Subjects were tested for reactive and voluntary saccades in separate sessions. Multi-voxel pattern analyses of fMRI data (discrimination between adaptation and reference paradigms) disclosed a network of cerebellar and parieto-frontal areas involved in saccadic adaptation, with marked differences between reactive and voluntary saccades. Notably, the oculomotor IPS was responsive only in the case of voluntary saccades adaptation. Second, the preliminary results of a fMRI-guided TMS study confirm the contribution of the oculomotor IPS in adaptation of voluntary saccades. Taken together, these studies suggest that, besides the well-documented contribution of the cerebellum, saccadic plasticity involves several areas of the cerebral cortex, including the oculomotor area of the intra-parietal sulcus.

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Anti-saccade adaptation

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Saccade accuracy is known to be maintained thanks to adaptive mechanisms. These mechanisms have been mostly studied for reactive saccades (RS). Fewer studies have addressed adaptation of voluntary saccades. In this study, we tested the possibility to adaptively increase the amplitude of Anti-Saccades (AS). Eight healthy subjects were submitted to a main adaptation task and 3 control tasks, performed in different sessions separated by 7 days. In all tasks, a visual target was presented randomly at 6, 9 or 12° in the right visual field and subjects had to shift their eyes toward the mirror location in the left field (AS). Adaptation of the leftward AS was elicited by presenting a feedback target immediately and systematically displaced relative to AS termination (10%). In this condition, repeated measures ANOVAs showed a significant increase of the amplitude of the left AS and the left RS. In control tasks, the time or the position of feedback target presentation was changed, failing to reveal any significant effect. In conclusion, this study demonstrates the possibility of inducing adaptation of AS, opening perspectives of rehabilitation of visual exploration deficits in hemianopia by an adaptative lengthening of saccade toward the blind field.

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Saccadic adaptation to moving stimuli

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The oculomotor system has access to two different types of visual target information, namely position and velocity. Two distinct types of eye movements are triggered by those signals, position errors induce saccades, whereas moving targets induce pursuit. Initially these two eye movements were believed to be controlled by two mainly independent circuits. In reality, successful tracking of a moving object is accomplished by a flexible combination of saccadic and pursuit eye movements. The interactive influence of position and velocity signals for pursuit suggests an influence of velocity signals also on the saccadic motor control. Therefore, the saccadic system should react with plastic changes to velocity signals. In the present study the intra-saccadic step of the classical McLaughlin paradigm of saccadic adaptation was replaced by a moving stimulus that induced a pursuing behavior after the saccade. In blocks of inward and outward movement trials the development of saccade amplitude modifications in response to the moving stimulus was analyzed. An inter-saccadic, long-lasting influence of moving stimuli on the saccade amplitude spanning several trials was shown as well as retention effects of the amplitude modifications. The adaptive changes are compared to the amplitude modifications induced by position errors in saccadic adaptation.

Eye position effects in saccadic adaptation in monkeys

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Saccadic amplitude can be adapted using intra-saccadic target steps in the McLaughlin paradigm. It is generally believed that after adaptation of a saccade of a certain amplitude and direction, saccades of the same amplitude and direction are all adapted to the same extent, independently from the initial eye position. This would be the case if plastic modulations of the visuomotor system were coded in a purely retinal reference frame. In our study two trained *Macaca fascicularis* performed reactive rightward saccades from five equally horizontally distributed starting positions. From these starting positions saccades of a fixed amplitude were made to targets which had the same retinotopic vector. In each session the saccades in one selective position were adapted to shorter amplitude, and the gain change of the saccades starting at the unadapted four positions were measured. The results show a decrease of adaptation when initial eye position differed from adapted position. We conclude that gain-decreasing saccadic adaptation in macaques is specific to initial eye position.

Saccadic adaptation-induced changes in visual space are coded in a spatiotopic reference frame

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The oculomotor system compensates for errors in saccades by a dynamic adaptive process that involves both the motor system and visual representation of space. To study the interaction between the visual and motor representations we designed a saccadic adaptation paradigm where the two representations were in opposite directions. We adaptively increased saccadic amplitudes for rightward saccades (outward adaptation), then measured the landing point for leftward saccades aimed at a target in the same spatial location as that used during adaptation training. These leftward saccades decreased rather than increased in amplitude, to land in the same spatial position as during adaptation, implicating that visual signals play a part in saccadic error correction. To examine the coordinate system of the visual signals, we designed a memory double-saccade task that dissociated retinal from spatiotopic coordinates. When the second saccadic target was presented to the same spatial but different retinal position, saccade landing showed strong adaptation; but when presented to the same retinal but different screen position, saccade targeting was unaffected by adaptation. We adapted saccades with the head oriented straight ahead and tested adaptation magnitude after changing head orientation either leftwards or rightwards. We found that saccades remained adapted in the same position in external space despite the movement of the head. These results suggest that saccadic adaptation fields are strongly influenced by the position of the target in the external world; and conversely, saccadic adaptation changes the memory representation of the visual field, which is encoded in spatiotopic coordinates.

Orienting Response

Mapping the distribution of neural activity in humans' oculomotor centres: A behavioural study

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Saccade metrics are computed based on the distribution of neural activity across populations of neurons in the topographic motor map of the Superior Colliculus. The large and overlapping receptive/movement fields of collicular neurons, and/or the possible spread of excitatory activity, do not prevent saccades to a single target to be accurate. However, it is responsible for the tendency to move the eyes in between simultaneously-displayed visual stimuli (or global effect). To map the distribution of neural activity in humans' oculomotor centres, we measured the maximal inter-stimulus distance for a global effect along various visual axes. During different blocks, a peripheral target appeared in different directions (0,23,45,67,80,90°), either in isolation or simultaneously with a less eccentric distractor on the same axis. Both the eccentricity of the distractor (2°,4°) and the angular separation between distractor and target (1-7°) were manipulated. The distractor deviated the eyes away from the target, but to smaller extents as stimuli moved from the horizontal to the vertical axis. The maximal distance for a global effect (~1mm of collicular surface on the horizontal meridian), was relatively constant across the map, but smaller near the vertical meridian. Thus, distributed neural activity in humans is horizontally biased, probably due to the neurons' receptive fields being horizontally-elongated.

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On the reduced influence of long distractors on saccade metrics: Evidence for inhibitory lateral interactions

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In most models of saccade generation, the computation of saccade metrics relies on excitatory and inhibitory lateral interactions within the motor map of the Superior Colliculus. Here, we assessed the role of inhibitory interactions in saccade generation by using a saccade-target task in which a to-be-looked-at peripheral target was presented with or without a distractor. To test the paradoxical prediction that due to lateral inhibition, larger distractors can induce less deviation than smaller ones, we varied the distractor length in its vertical dimension, while holding constant the distance between distractor and target. Results confirmed that when a distractor was presented along with a target stimulus, the saccade's landing position shifted toward the distractor. The important fact was that the deviation increased with distractor length, but only up to a critical length; above this length, the effect reversed that is longer distractors led to progressively smaller deviations. These results suggest that inhibitory interactions play a critical role in determining saccade metrics; they can decrease the weight of a distractor in the spatial integration of distractor and target locations, at least when the neuronal activity pattern induced by the distractor is wide enough.

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The sequence of decoding population responses in the superior colliculus

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In attempting to understand the events that occur during the generation of saccades, we constructed and tested two commonly stated oculomotor decoding models, vector averaging (VA) and center-of-mass (CM). To produce accurate saccade each model must incorporate a decoding mechanism to decipher population responses in the superior colliculus (SC), and an exponential transformation to convert activity from the SC. The order of implementation for these two criteria is different within each model. We seek to distinguish between each decoding sequence and determine the order of events necessary to generate accurate saccades. To quantify the predictions of each decoding sequence we implemented and simulated each model in Matlab. Simulations revealed that distinguishing between the two models is not straightforward when decoding a single population response, but can be appreciated when decoding two simultaneous population responses. We experimentally validated the predictions of each model by observing saccade endpoint distributions generated from weighted, simultaneous stimulation of two sites in the SC. Analysis of the elicited distributions revealed a consistency with the predictions generated by the decoding sequence of the VA model.

Subcortical saccadic selection processes: A model of the tecto-basal loops

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The Superior Colliculus (SC) is a well-known generator of saccadic movements. Its reciprocal connectivity with the Basal Ganglia (BG) has recently been emphasized [McHaffie et al., 2005, Trends in Neurosciences, 28(8), 401-407], as well as its implication in selection processes [McPeck & Keller, 2004, Nature Neuroscience, 7(7), 757-763, among many other papers published since 2000]. Regardless of the role of the BG in selection, numerous experimentalists suggested that selection in the SC results of lateral inhibitions. Arai and Keller [2004, Biological Cybernetics, 92, 21-37] have hypothesized that the BG could play an important role in the selection of targets in a purely subcortical SC-BG circuit, but did not propose a full functional model of this circuit. We investigate the possibility that selection in the SC results from SC-BG interaction, using a model linking together recent SC [Tabareau et al, 2007, Biological Cybernetics, 97, 279-292] and BG [Girard et al., 2008, Neural Networks, 21, 628-641] models. We aim at reproducing experimental data gathered by McPeck and Keller (2004) regarding deficits in target selection after inactivation of the SC. The model proposes an architecture for SC selection using subcortical circuitry only, sufficient to explain the experimental results.

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Characteristics of saccadic intrusions that were induced by a high mental workload task

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The first half of this research demonstrated that increased levels of mental workload task induced more saccadic intrusions (SI or microsaccades larger than an amplitude of 0.4 deg in visual angle). Mental workload was imposed using an auditory N-back task. All participants (N=11) showed more saccadic intrusions in a higher N-back task compared to a lower N-back task. In the second half, we report detailed analyses of the characteristics of the saccadic intrusions that were produced by the N-back task. Consistent with the results of Abadi and Gowen [1999, *Vision research*, 44(23), 2675-2690] and Engbert [2006, *Progress in Brain Research*, 154, 177-192], the saccadic intrusions we observed had gaze deviations mostly in the horizontal direction with SI dwell periods of up to 870 ms. However, amplitudes of the SI's were different from those reported by Abadi and Gowen, who found that SI amplitudes ranged up to 4.1 deg. In our study, we found that low mental workload task rarely induced SI's with an amplitude over 4.1 deg, while a high mental workload frequently induced SI's with amplitudes over 4.1 deg. Our research indicates that the mental workload level needs to be systematically controlled when SI characteristics are studied.

Target eccentricity and saccadic error influence the latency, amplitude and orientation of secondary (micro-)saccades

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During fixation small saccades cause a rapid shift of the retinal image with an average frequency of one to two times per second. The implications of these small eye movements are not well understood. While previous research mainly relied on purely fixational tasks, we examine how factors related to the previously executed primary saccade influence the latency, amplitude and orientation of secondary (micro-)saccades. In our experiment subjects were instructed to move their eyes to an upcoming target (at a distance of either 6 or 14 degree of visual angle) and hold fixation at the new position until the end of a trial. We replicate that characteristics of secondary (micro-)saccades are largely determined by the magnitude of the saccadic error and whether the eyes under-/overshoot the target. Furthermore, we extend previous results by the finding that these effects are strongly modulated by the initial target eccentricity. The results are interpreted within the architecture of a model which has recently been introduced to account for the generation of microsaccades [Rolfs et al., 2008, *Journal of Vision*, 8 (11), 1-23].

Influence of eye position on spatial representations

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It has remained controversial whether spatial representations make use of eye position signals. One way to investigate this issue is to determine whether spatial representations are updated during fixation, as the eye changes position because of ocular drift. In complete darkness, humans exhibit idiosyncratic drifts which appear not to be controlled nor monitored by the oculomotor system. While it has been recently shown that motion perception judgments during fixation do not rely on motor knowledge of ongoing drift [Poletti et al., 2010, *Journal of Neuroscience*, 30(33), 11143-11150], it remains possible that a signal associated with the eye displacement might be available to the motor system and used to update spatial representations. In this study, we examined whether the occurrence of drift in complete darkness influences the execution of saccades to remembered locations. Saccades were executed after a temporal delay of 2 s, a period in which ocular drift moved the eye away by 40' on average from its initial position. We show that a delayed saccade is modulated by the occurrence of drift and partially compensates for the resulting displacement. This finding suggests that eye position signals are registered during fixation and used to update spatial representations driving saccades.

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Orienting Response: Clinical

The attentional bias of emotional pictures in antisaccade and go/no-go tasks

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Attentional bias of emotional pictures describes a robust finding where an emotional picture has high priority in capturing viewers' attention when it is presented simultaneously with a neutral picture [Nummenmaa et al., 2006, *Emotion*, 6, 257-268] or when it is presented individually [Kissler & Keil, 2008, *Experimental Brain Research*, 188, 215-222] in several tasks. In the current study we recorded participants' eye movements to explore the attentional bias of emotional scene pictures in saccadic tasks when they were presented individually. In an antisaccade task, when emotional pictures as compared to neutral pictures were presented as the peripheral stimuli, participants made slower correct antisaccades and more erroneous saccades to the stimuli. In a go/no-go task, a scene picture was presented in the centre of the screen following the central fixation point, and a coloured square appeared simultaneously in the parafoveal region as the target stimulus. Participants made slower correct saccades to the emotional scenes compared to the neutral scenes in the go task and less erroneous saccades to the emotional scenes compared to the neutral scenes in the no-go task. The results showed that the attentional bias is seen in both the reflexive (errors) and voluntary (latencies) orienting systems.

Socio-cognitive load and social anxiety: Processing efficiency and performance in an emotional antisaccade task

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Preliminary evidence suggests that social anxiety may lead to difficulties inhibiting emotional and neutral faces, resulting in performance errors on the antisaccade task [Weisser et al., 2009, *Cognitive, Affective, & Behavioral Neuroscience*, 9 (3), 314-322]. We investigated the effect of social anxiety, emotional salience and socio-cognitive load on the performance of 72 participants in an antisaccade task with angry, happy and neutral faces preceded by non socially threatening sentence primes which were positive self-referential (e.g. 'Sara is impressed by your speech'); negative non-self-referential (e.g. 'Sara is annoyed with her boss') or neutral (e.g. 'Sara takes the train to work'). Despite no group differences, latencies were significantly longer for happy than angry faces and fewer errors were corrected when the face was preceded by a positive self-affirming prime than a negative non-threat or neutral prime. We interpret these results as being consistent with an approach-avoidance response for positive and threatening social information. However, high anxious participants made more erroneous antisaccades to neutral than valenced faces. This suggests that increased socio-cognitive load may alter the previously observed error pattern (i.e. Weisser et al. 2009), with high anxious individuals avoiding emotional faces, but finding it more difficult to inhibit ambiguous faces.

Volitional inhibition to emotional stimuli in people with depression: Evidence from the antisaccade task

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Most previous research indicated that impaired inhibition to emotional stimuli was one of the important cognitive characteristics of depressed individuals. This study aimed to investigate the volition inhibition to emotional stimuli in people with depressed mood (DM). Based on the scores of the Beck Depression Inventory and the Self-rating Depression Scale, participants were divided into a DM group and non-depressed (ND) group. The antisaccade task which was composed of a prosaccade task (PS) and an antisaccade task (AS) was conducted to examine the inhibition abilities by varying the arousal level of volition (low and high) of the tasks, with happy, neutral and sad facial expressions as stimuli. Results showed that at the low volition level in the AS condition, the correct saccade latency in the DM group was significantly slower than in the ND group ($p < 0.01$). The DM group had reliably higher direction error rates in response to emotional faces, especially for sad expressions ($p < 0.01$). However, the differences disappeared in the high volition level antisaccade tasks ($p > 0.05$). These results indicated that the impaired inhibition to emotional information, particularly sad information, was one of the important cognitive characteristics of DM. The impaired abilities were repaired in the high arousal level of volition.

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Predictive mechanisms during pursuit in psychotic disorders

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The pursuit system represents a valuable model for studying sensory transformation within a well-characterized neural circuitry. Besides sensory input derived from retinal signals, extraretinal mechanisms including prediction and the storage of eye velocity are used to optimize pursuit performance. While earlier studies have suggested an impairment of extraretinal processing in schizophrenia, more recent studies suggest that predictive mechanisms can be used by patients to overcome sensory transformation deficits. The present study assessed patients with schizophrenia (N=18) and matched healthy controls (N=22) on blocks of predictable pursuit ramps at 8°/s and 16°/s. Three different aspects of prediction were evaluated by blanking off the visible target either at the beginning, the middle or the end of ramps. Pursuit latency did not differ between groups, patients revealed reduced eye acceleration during the first 400 ms of pursuit and optimal gain was reduced. Residual gain during the blanking period was lower in patients. Velocity decreased slower in patients after the target had been blanked off, indicating that patients rely on short-term velocity storage to continue an ongoing movement to a higher extent than healthy controls. This implies that under certain circumstances distinct predictive mechanisms are used by patients for optimizing their performance.

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Long latency and high variability of accuracy-speed of prosaccades in Alzheimer's disease at mild to moderate stage

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Study of saccades is a useful tool to investigate brain function. There is still controversial view for deficits in prosaccades in Alzheimer's disease (AD) and there is no study of saccades in subjects with mild cognitive impairment (MCI). Saccades were recorded in 10 healthy elderly, 9 subjects with MCI and 9 patients with AD. Two tasks were used: the gap (fixation target extinguishes prior to target onset) and the overlap (fixation stays on after target onset). Eye movements were recorded with the Skalar IRIS system. Results showed: 1) latencies were shorter in the gap than in the overlap task (a gap effect) for all three subject groups, healthy elderly, MCI and AD; 2) latency of saccades was longer for AD patients than for healthy and MCI subjects; 3) accuracy and mean velocity were normal in MCI and AD subjects, however, variability of accuracy-speed was higher for AD patients than for healthy and MCI subjects, in the overlap task. Abnormalities of reaction time and accuracy-speed variability reflect deficits of cerebral areas involved in the triggering and execution of saccades; saccade test can be useful to follow up the evolution of MCI subjects as some of them may develop AD disease.

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Are effects on saccade latencies preserved in the homonymous hemianopia? Evidence from gap and remote distractor effects

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Latencies of saccadic eye movements in hemianopic patients, suffering from a loss of the visual field contralateral to a unilateral occipital lesion, were compared to those of matched healthy controls. Participants were asked to detect and to make a saccade towards a visual stimulus briefly displayed at 5° or 9°, in the left or right visual field. In some trials, a second stimulus (the remote stimulus) was presented in the other hemifield (i.e., bilateral presentation, at 5°). Blank trials were interleaved. A gap procedure in which the central fixation point offset was either simultaneous to or preceded target onset by 200msec was used. In controls: 1) the gap-200msec procedure evoked express saccades compared to the gap-0msec procedure; 2) presence of the remote stimulus increased latencies compared to single stimulus presentation (remote distractor effect); 3) the remote distractor effect suppressed express saccades. In hemianopes, targets were not perceived consciously but still able to generate saccades. Latencies were longer than in controls and express saccades did not occur (regardless the hemifield) in spite of a preserved gap effect in the intact hemifield. Finally, the remote distractor effect was not observed. These preliminary results suggested alterations of temporal parameters of saccades.

Vergence & Binocular Eye Movements

Stability of vergence accommodation and accommodative vergence assessment

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Accommodation and vergence are two components of the oculomotor system that are cross-linked. This interaction is held by the accommodative vergence (vergence induced by accommodation) and by the vergence accommodation (accommodation induced by vergence), respectively assessed through *AC/A* and *CA/C* ratios. Repeating the measurements, those ratios may vary due to the procedure and to physiological variations or to adjustments of the oculomotor cross-links. In order to further analyse such variations, *AC/A* and *CA/C* measurements were assessed daily during three days using laboratory (haploscopic) and clinical procedures. Subjects had routine activity during the three day period of test. Any variation on the test values is assumed to be due to the procedure and to physiological variations. For each test (haploscopic stimulus *AC/A*, haploscopic response *AC/A*, clinical *AC/A*, haploscopic *CA/C* and clinical *CA/C*), a confidence interval is provided that covers the range of measurement and physiological variation. By contrast, adjustments of the oculomotor cross-links would result in larger changes.

Visual acuity measurements and eye movements: Changes in fixation parameters in the course of approaching the threshold

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It is known that, while scanning test charts, subjects respond more and more slowly as they approach the threshold size. Our task was to study the eye movements that accompanied the process of examining line by line the test charts including symbols both larger and smaller than the subject's threshold. Eye movements were recorded binocularly with the iView X system (SMI). Two types of the test charts were used: (1) standard commercial charts with proportional design and 5 symbols per line; (2) original charts with regular design and 10 symbols per line. In the first case, the spaces between the symbols were equal to their width; in the second case, the spaces were much larger. The results obtained in 5 adults (19-50 yr) demonstrated the anticipated significant increase in the time spent on each symbol with decrease in size. However, there was a great inter-individual variability in duration of eye fixations on large (500-1200 ms) and small (1000-4000 ms) symbols. The degree of concurrence of the left and right eye trajectories usually decreased with decreasing stimulus size but also depended on experimental conditions, history of testing and subject's fatigue.

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Eye movements and visual acuity in phorias

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Phoria (latent misalignment of the eyes) is common in unselected populations. If decompensated it often results in symptoms of asthenopia: headache, dizziness and fatigue. To specify challenges phoria induces for binocular saccadic coordination we recorded asymmetrical saccades in subjects with (de-)compensated phorias and compared eye position statistics to normals. Furthermore we measured visual acuity to estimate possible consequences of post-saccadic binocular misalignment. Eye movements in darkness were recorded with video-oculography (EyeSeeCam). Baseline visual acuity was determined in a forced choice task by optotypes that flashed for 100ms on a central screen at 4m distance. In the saccade paradigm subjects performed asymmetrical saccades between lateral near-targets (50cm distance, 10° left/right) and the screen. To measure post-saccadic visual acuity optotypes flashed on screen immediately after saccades. Experiment recordings in 10 normals (7 male, 3 female, 30+/-7.75 years) showed significant differences (ttest: $p < 0.001$) between visual acuity at baseline (mean+/-sd: 1.90' +0.29' /-0.25') and post-saccadic acuity (8.19' +2.73' /-2.05'). Vergence movements continued during post-saccadic optotype presentation: The eyes diverged from 2.5+/-1.42° vergence (optotype onset) to 1.21+/-1.18° (offset) at 13+/-5.16°/s. Conclusion: Already in normals visual acuity is significantly deteriorated after asymmetrical saccades. Comparison to patient data will be presented on the poster.

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Effects of image disparity on vergence, perceived immersion, and viewing symptoms in stereoscopic gaming

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In stereoscopic viewing, images with spatial disparities are afforded to the two eyes to enhance depth perception. A conflict between accommodative and vergence demands arises from such a condition, and might be responsible for perceived viewing discomfort during stereoscopic viewing. To test this, participants played paired the same game in 2D mode, and in 3D mode with different amounts of image disparity. They were asked to compare their perceived immersion and viewing symptoms in 2D and 3D sessions. Vergence eye movements were measured during gaming sessions and related to the amount of image disparity and perceived immersion and symptoms. Results show that larger image disparity resulted in closer convergence and heightened immersion and symptoms until a break point was reached. Younger and exophoric viewers incurred greater convergence and more severe symptoms with larger image disparities than older and esophoric viewers. The pivotal level of image disparity depends on viewer's convergence abilities and their age. These findings suggest that in stereoscopic viewing, convergence amplitude and convergence abilities are critical in determining perceived immersion and symptoms. To appreciate stereoscopic content while attenuating viewing discomfort, the amount of image disparity should match the viewer's visual abilities.

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Sensory and oculomotor components of fusion capabilities at various distances: Inter-subject variability

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Development of 3D technologies poses a number of problems concerning perception of virtual reality. To avoid subject's discomfort when viewing stereoscopic images, it is important to assess more thoroughly a number of his binocular capabilities, in particular - his fusional reserves. The purpose of this study was to analyze the results of measuring divergent fusional reserves at various distances and to assess the contribution of sensory and oculomotor components. Measurement of fusional reserves in the same subjects was performed by means of two different methods for the left/right image separation: using a synoptophore (1); employing 3D monitor (HYUNDAI) with circular light polarization and appropriate software (2). Eye movements were recorded binocularly with the iView X system (SMI). Comparative analysis of the results obtained in 10 adult subjects at various distances revealed a significant variability in subjects' capabilities as concerned both common divergent reserves and actual divergence of the visual axes at far and near. Noteworthy, in trained subjects, actual divergence of the visual axes at near distances was as large as at far distances, despite a stronger conflict between the stimuli for accommodation and vergence.

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Quantifying depth bias in free viewing of still stereoscopic synthetic stimuli

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In studies of 2D visual attention, eye-tracking data show a so-called "center-bias", which means that fixations are biased towards the center of 2D still images. However, in stereoscopic visual attention, depth is another feature having great influence on guiding eye movements. Relatively little is known about the impact of depth. Several studies mentioned that people tend to look at the objects at certain depth planes. Therefore, it is reasonable to suppose the existence of a "depth-bias". But studies proving or quantifying this depth-bias are still limited. We conducted a binocular eye-tracking experiment by showing synthetic stimuli on a stereoscopic display. Observers were required to do a free-viewing task through active shutter glasses. Gaze positions of both eyes were recorded for obtaining the depth of fixation. Stimuli were well designed in order to let the center-bias and depth-bias affect eye movements individually. Results showed that the number of fixations varied as a function of depth planes. There was also a relationship between the duration of fixation and the depth plane where the objects were located.

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An eye-movement-defined hierarchy of visual stimuli

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Reverse correlation of stimulus velocity with eye velocity can be used to infer pursuit latency in a task in which a subject attempts to follow a target undergoing random motion. Using a binocular dual Purkinje image eye tracker equipped with stimulus deflectors, we measured tracking responses to four-dimensional motion, produced by delivering an independent random walk to each eye, analyzing the results in terms of horizontal and vertical vergence and version. High-contrast luminance-defined stimuli produce the shortest latencies (around 100 msec); varying texture contrast increases the delay by approximately 50 msec / log unit. Nulling the first-order luminance contrast in a second-order contrast-modulated target produces a dramatic increase in latency (over 100 msec additional delay), and abolishes the vertical vergence response - the only one of the four types of movement that cannot be executed voluntarily. We propose a model of the system in which a fast reflexive system responds to a limited class of stimuli, while a slower voluntary system is capable of tracking anything that can be seen.

Eye-Tracker Comparisons

EOG-based gaze position estimation and comparison with a commercial video-based eye-tracker

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The ElectroOculoGram (EOG) is a well-known physiological signal whose variations are highly correlated with eye position. We propose here to use such a signal to build a new real-time gaze position estimator in the context of video viewing. A complete methodology to design the EOG-based gaze tracker is therefore described. A first step performs on-the-fly denoising including natural baseline drift and blinks removal. The gaze position estimation is then performed using two complementary signals obtained by filtering the raw EOG in two different spectral bands associated with slow and fast eye movements. Such an approach allows to efficiently catch the different eye motions (fixations, saccades and pursuits movements especially) and leads, after calibration, to an estimate of the user's gaze position on the screen. EOG and video-based gaze tracking are finally simultaneously performed in static, dynamic and free viewing situations to evaluate and compare the proposed methodology. Encouraging results are obtained showing an EOG-based estimation of the gaze position compatible with the targeted context.

Comparison of reported gaze dynamics between a scleral search coil and a video-based eye tracker

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Analyzing eye movements during (visual) stimulation has become the methodology of choice for many researchers in vision science and beyond. Scleral searchcoil systems have been considered the "gold standard" regarding precision and signal to noise ratio, at the cost of pronounced setup overhead and a certain degree of invasiveness. Camera-based eyetrackers are easy to use and non-invasive, yet they are still considered to be more noisy and less precise. We compared a scleral searchcoil-based eyetracker (DNI) and an up-to-date infrared camera-based eyetracker (SR Research Eyelink 1000) by simultaneously recording human eye movements with both techniques. During multiple 4s-periods of fixation, the search coil system reported less fixational position variability (standard deviation of position (Subject 1/2): horizontally EL0.24deg/0.16deg, SC 0.2deg/0.13deg; vertically EL 0.28deg/0.22deg, SC 0.14deg/0.17deg). Saccadic eye movements differed: averaged across subjects and saccade lengths, the camera-based system reported higher peak velocities, but lower relative standard deviation in both horizontal (EL: 474deg/s±30.0% SC: 324Deg/s±37.2%) and vertical (EL: 395deg/s±34.6% SC: 287Deg/s±40.3%) directions. However, the camera-based system frequently reported a very pronounced wobble (amplitude >1deg) around the end point of both horizontal and vertical saccades, which was completely absent in the data reported by the search coil system.

Parallax error in mobile eye trackers

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The results of analysis of video-based eye-tracking method using Dark Pupil technique in mobile devices (SMI IVIEW HED) are presented. We used two most common distances on which experimental data is usually collected: short-range 0.75 m and long-range 1.5 m. The subject was shown two tables (one for each range) each about 30° in the visual field. Deviation of POG (point of gaze, shown by tracker) from each point of table was measured. The average accuracy was 10.42 pixels for 0.75 m and 16.09 pixels for 1.5 m. We also registered POG for about 30 seconds on artificial and living eye (subject was asked to gaze at a point). Standard deviation for the artificial eye was 3.1 pixels (0.16°) and 7.84 pixels (0.4°) for the living eye. The cause of parallax error appearance in the system is the different locations of points from which optical axes of eye and outer video camera go out. This difference is comparable with demonstrated objects' sizes. So the investigator may face a much bigger error than the apparatus one. This error (BE) can be measured using the formula $BE = CD * (CA - CB) / CA$, where CD is the distance between pupil and camera lens centers, CA is the distance of calibration, and CB is the distance between subject and object.

Recording two-dimensional eye movements: Remote infrared eye tracking versus scleral search coils

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The scleral search coils are the golden standard in measuring high precision eye movements. In our lab, we apply less intrusive remote eye tracking. This study compared the performance of an infrared based remote eye tracker (TX300, Tobii, Sweden) with the scleral search coil method. Two-dimensional eye movements were simultaneously recorded at a sample frequency of 300Hz using both systems during 45 point grid fixations and visually-guided saccades. Both systems were synchronized using a photocell placed on the TX300 monitor combined with displaying white screens in between stimuli. The photocell's output was simultaneously sampled with coil output, while the TX300 registered timing of white screen display in an event list (synchronization accuracy of 7ms). For fixations, we found an accuracy in horizontal gaze position of $0,0 \pm 1,6^\circ$ (mean \pm 2SD; TX300) and $0,1 \pm 1,0^\circ$ (Coils). In vertical position, an accuracy of $-0,5 \pm 1,6^\circ$ (TX300) and $0,0 \pm 1,0^\circ$ (Coils) was found. The difference in saccade duration was 8 ± 40 ms (TX300-Coils). For maximum saccade velocity, we found a difference of $64 \pm 188^\circ$ /s. We conclude that the TX300 is an accurate system for measurement of eye positions. For assessing accurate eye movement dynamics, we suggest additional signal filtering, especially in vertical direction.

Quantification of the effects of calibration method and eye factors on eye-tracking accuracy

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This study investigates the effects of different calibration methods, and how much common obstacles like glasses and contact lenses decrease tracking quality. We recorded 149 participants performing a reading task using a tower-mounted dark-pupil system. The participants were randomly assigned one of three different calibration methods: manual operator calibration, manual participant calibration, and automatic system-controlled calibration. Information about eye colour, eye dominance, mascara, visual aids, eye lashes were also collected from the participants. The data were explored using a linear mixed-effects model, modelling the change in tracking accuracy, tracking precision and amount of data loss. The results indicate that a participant-controlled calibration performs best, followed by an operator-controlled calibration, and the worst calibration is performed by an automatic system-controlled calibration. Although it is common knowledge that factors such as mascara and glasses are problematic, our results can quantify that, among many things, the mean increase in offset, for the system used, by mascara was 14° , whereas downwards-pointing eye lashes caused an offset increase of $.38^\circ$. Although some researchers prefer, and even recommend, participants to wear contact lenses rather than glasses, the results show that lenses increase offset by $.52^\circ$ and glasses only by $.36^\circ$.

Web Search & Applied

Children's exposure to, and perceptions of, online advertising

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This study of Swedish teenagers, 14-16-years old, aims to discuss youth's potential, actual, and perceived exposure to Internet advertisements. In order to capture the children's potential and actual exposure to online advertising, teenagers' eye movements have been measured while surfing on Internet for a period of 15 minutes. Retrospective interviews were then carried out, in order to assess the children's perceived exposure. A total of 44 students participated in the study. The surfing sessions took place in a naturalistic setting. Each subject made an average of 76,89 browser requests during the 15 minutes session. In total 5161 advertisement instances were identified and coded into 11 categories. The largest category was Ad links (33,8%), the second largest was Technology (14,39%). Gambling (11,15%) came third. Over an entire session the average number of potential exposures to advertisement was 132, but the number of actual exposures was not more than 13,69 advertisements. Thus the teenagers visually attended to about 10% of the potential number of advertising exposures. The retrospective protocols revealed that there were substantial differences between the children's actual and perceived exposure to advertisements.

How display technology affects reading behavior: A comparison of electronic paper and LCD screens

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The market of mobile eReading devices is rapidly evolving. Different display types with different characteristics, e.g., resolution or reflection/glare, are currently available. We compared three available display types regarding their effects on oculomotor behaviour during reading. The displays tested were e-Ink without touch sensitivity, e-Ink with touch sensitivity and backlit LCD with touch sensitivity. To this end participants read on each display a few pages of text displayed with dark letters on light background. Eye movements were recorded using an infrared video eyetracker and mapped on the respective displays for subsequent analysis. While mean fixation duration was constant on all three display types, results revealed significant differences in reading speed and the proportion of regressive fixations. Specifically reading speed was higher, and the proportion of regressive saccades was lower, on the LCD compared to e-Ink displays. We conclude that under certain circumstances LCD screens are well suited for reading.

Screen selection and meta-cognitive error in a quadruplex video observation task

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Compared to assessment of observer performance during single screen video observation, multiplex format has been relatively neglected. Such layouts are common in security settings, yet the visual consequences of such layouts for detection are, as yet, not fully understood. We recorded eye movements of 10 naïve observers during a quadruplex screen surveillance task using a modified SMI iView HED, 200Hz. Observers monitored four 1-minute clips simultaneously in multiplex with one screen containing an incident of petty theft. For single screen presentation, 10 other observers showed a detection rate of 40%, however the quadruplex format rendered the incident undetectable (0%). Patterns of initial fixations showed a sequence of screen fixations proceeding in a left-right, top-to-bottom sequence for the majority of observers. Pre and post-observation ratings of detection confidence were obtained for single and quadruplex participants, and a cross-over interaction was observed. Initially low ratings of confidence for single screen observers changed positively after the test phase; and vice versa for quadruplex viewers. The results are consistent with previous reports of metacognitive error [Levin, et al. 2000, *Visual Cognition*, 7(1,2,3), 397-412].

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The influence of text visualization on the screen on eye movements and information processing

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Since the last decade Internet has become a rapidly growing source of professional and scientific information. This trend necessitates defining new standards for presenting sophisticated texts to facilitate their efficient processing. The experiment involving 40 participants presented in this paper investigates the influence of text visualization on text recall. We contrasted text scrolling versus dividing paragraphs into separate screens and additionally provided call-outs for both conditions. The dependent variables were derived from a text recall test conducted at the end of the experiment combined with eye tracking data regarding average fixation and dwell time. Sensory processing was tested using word recognition tasks, whereas the semantic level was examined using synonyms and multiple choice questions. Based on results, we argue that visualization techniques are likely to facilitate information processing on the sensory and semantic level. Eye tracking data shows differences in reading efficiency; it was observed that scrolling required more processing time compared to reading text divided into screens, while the results from a recall test remained almost identical. More specifically, participants from the latter group memorized more words that had never appeared in the original text. In addition, differences in eye movements were particularly distinct in the last paragraphs.

Eye movements while viewing dynamic traffic information panels

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In the US, information about critical traffic situations is often conveyed through portable changeable message signs (PCMS), consisting of a black rectangular screen on which three lines of up to eight letters can be displayed. The standard ordering of information on PCMS devices is "cause," "distance," and "action" (e.g. "DETOUR," "1000 FT", "TURN RIGHT"). We suspected that an alternative order in which the required "action" is presented first would result in faster and more accurate responses. We also hypothesized that the standard display duration of 3 seconds per phase may be too fast for elderly drivers. We collected eye movement data while participants viewed photographs of PCMS devices with varied message presentation orders and responded by pressing the corresponding right or left trigger buttons on a gamepad. We found that, indeed, the alternative order resulted in higher accuracy and faster responses, suggesting that providing drivers with information of the immediate action required results in greater compliance. Furthermore, younger adults displayed less fixations per trial, increased fixation durations, and lower regression rates, compared to middle and older adults. We conclude that eye movement analyses can serve as a useful tool to suggest improvements for traffic information systems.

Understanding how people make decisions: An approach based on eye movements during a task of information search

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Knowing where web users are looking at while searching for information is essential for usability purposes [Baccino et al., 2005, Hermes Science]. We carried out an eye tracking experiment to learn how people look for information and make decisions. Given a goal and a set of paragraphs, we asked participants to find the most related paragraph to such goal. A pair of paragraphs is displayed and the participant should choose the most related. The paragraph chosen is kept and the other one is replaced by a new randomly chosen paragraph. We found two different behaviors: collecting information (reading without knowing the other paragraph to compare to) and comparing information. Participants show more fixations and longer durations in the comparison behavior than in the collecting one. Moreover, results showed that there is not an important effect on participant's decision of whether a paragraph is displayed first or second or displayed on the left or right side. Finally, our data shows that the "gaze cascade effect", phenomenon which involves the gradual gaze shift toward the item that is chosen as more "attractive" [Shimojo et al., 2003, Nature Neuroscience, 6, 1317-1322], does not seem to occur in such a decision task on textual material.

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Dynamic display changes interrupt decision process and alter decision outcome

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To attract consumer attention, shopping websites often involve the use of dynamic displays such as flashing or rotating text. While some experimental evidence supports the effectiveness of dynamic displays on capturing attention, dynamic changes might also distract the user and hinder task performance. We attempted to examine the influence of display changes on sequential visual decision making tasks. In 2 experiments, participants' eye movements were monitored while they chose between 2 alternatives, each represented by a set of visual images, with one set placed on the top of the screen and the other on the bottom. Immediately prior to this decision, participants performed one or more binary decisions based on subsets of these images. On some trials, images were spatially swapped in the display presented during the final decision as compared to a prior presentation. In the critical condition, this swap caused images to be linked to different alternatives (top or bottom) during the initial decision versus the final decision. By analyzing behavioral and eye movement measures, we documented evidence that participants flexibly and effectively accommodated to a variety of display changes. However, there was cost associated with display changes in the form of longer viewing times and decision reversal.

Communication

Fixation based comparison of static and dynamic agent-based deictic gaze cueing

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Static views of head and eye gaze allocate observer attention in the direction of agent gaze [Langton, et al., 2000, *Attention and Performance*, 4(2), pp. 50-59], but can a computer generated agent create effective, procedural sequences of deictic gaze and head cueing? Previous research has focussed on static images using manual response paradigms. We measured the efficacy of a static, two-frame or fully animated agent to orient observer gaze response to peripheral targets using agent head and eye-gaze cues. We assessed the location of the post-cue first-fixation of the observer to eight targets that were positioned radially around the agent's head displayed on a monitor. Participant eye-movements were recorded with a modified SMI-HED system. The first-fixation time responses to animated agents were faster than to static or two-frame sequences of agent gaze. Observers' fixation responses were accurate in 92% of trials. This suggests that use of first-fixation to assess response is a valid, non-haptic, input paradigm that shows how immediate and direct the allocation of attention can be in gaze cue directed agent-based interaction. The data suggest that procedural deictic interaction can be enhanced in with motion, or more precisely with believable agent animation.

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Shared perception of facial expressions and patterns of eye movements during remote dyadic communication

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We propose nonclassical method to study categorical perception using joint decision making based on individual identifications of visual stimuli. Participants in pairs observe same or different images synchronously presented (3 s) to each of them on separate displays. The task is to discuss the stimuli without seeing each other's displays to make joint decision about images equality. Images used are stills from high speed video record of an actor performing transition between emotional facial expressions. Before the experiment all images are presented in natural order (3 s each) to get participants acquainted with the stimuli sequence. Eye movements and pupil apertures are registered using SMI HiSpeed 1250 and HED eye trackers. We plan to: (1) explore categorical effect of joint perception of one-step pairs along the transitional continuum (lower performance for stimuli close to "pure" prototypical expressions - ends of continuum); (2) describe types of eye movements patterns in situation of dyadic communication; (3) by analyzing participants' verbal activity, reveal the interaction strategies and their influence on task performance and eye movements patterns; (4) explore the pupil aperture changes related to categorical perception; (5) compare the performance data with that of individual psychophysical experiments on natural and morphed facial expressions.

Eye-tracking and bio-signal study of human-ECA interaction

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Eye-tracking exploration of simulated interaction with two versions of embodied conversational agents (ECA) are reported. The study is aimed at the evaluation of the quality of interaction (immersion and believability) between a human user and recorded question answering by an ECA. The evaluation is based on the analysis of the zones attended (face, hands, and other body parts of the agent). Simultaneously, bio-signals have been recorded giving information about the emotional state of the human users. The results show, that this approach can give valuable information which could inform the design of human-computer interfaces.

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In search for the optimal communication of attention in remote cooperation: Gaze versus mouse transfer

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Despite numerous studies investigating gaze input in human computer interaction, only little is known about its usefulness for cooperative purposes. In spatial tasks advantages of gaze transfer in contrast to purely verbal interaction have been reported, while the more critical comparison with simple mouse pointing is still missing, or sometimes revealed no advantage at all. To investigate the potential for gaze transfer to be successful, a task was used where knowledge about the partner's search process—rather than just its result— was crucial. Pairs of participants had to select one of six possible paths, depending on different features of the stimuli located on them. One participant (searcher) had all the information that was necessary to solve the task —shown in a small, movable window. The other participant (assistant) had to move this window across the screen based on the searcher's eye or mouse position transfer. Cross recurrence analyses of the eye and mouse movements suggest that in the mouse condition searchers simply coupled their mouse cursor to their gaze, i.e., they simulated gaze transfer. Based on these results, the utility of gaze transfer in remote cooperation is discussed anew, focusing on a thorough comparison of both transfer types.

Avatars, agency and mutual gaze: Effects on eye contact, task performance and perceived social presence

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Mutual gaze, or eye contact, is a fundamental aspect of social interaction, and is known to facilitate task performance. It is also believed that mutual gaze is related to social perceptions of one's interlocutor. In order to establish how much looking by one conversational partner at another will maximise the amount of mutual gaze between the pair, users interacted with a programmed agent within *Second Life* to solve simple arithmetic tasks. This agent was programmed to look at the user during 0%, 33%, 67% or 100% of the interaction, and the amount of mutual gaze between the pair was recorded, along with the task performance measures. In order to manipulate purported agency, prior to the interaction users were either told that the agent they were interacting with was human-controlled (an avatar) or computer-controlled (an agent). Social presence measures were taken, in the form of questionnaires administered during the interaction. The relationship between the amount of mutual gaze, purported agency of the interlocutor and reported social presence was investigated, and the implications for mutual gaze and its relationship to social and task-related measures were discussed.

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Invited Talk

Why do we need mathematical models in eye-movement research?

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The development of rigorous mathematical concepts is often taken as a measure of maturity of a scientific discipline. While this general perspective might apply to all fields of science, I will propose that modeling helps to investigate three critical problems specific to eye-movement research: explanatory level, generalizability, and reductionism. Each of these aspects of mathematical modeling will be illustrated by a specific example. **Explanatory level:** The range error observed for saccadic eye movements has been described as a phenomenon of the oculomotor system. However, it was difficult to identify general principles for the range error across tasks. Using a Bayesian modeling approach to oculomotor control in reading, we generated new insights on the mechanisms underlying the saccadic range error. Most importantly, in the Bayesian model, the explanatory level was moved from the motor level to the perceptual level. **Generalizability:** Competing mathematical models for eye movements in reading were developed over the last 10+ years. To evaluate and compare these models, simulation studies of saccade generation are currently applied to a variety of reading and scanning tasks. Examples are cross-language comparisons, scanning tasks, or shuffled text. Therefore, model generalizability has evolved into a key concept for eye-movement research. **Reductionism:** Fixational eye movements are classified as microsaccades and slow components (physiological drift and tremor). For more than 30 years, it was difficult to identify specific motion-generating principles underlying both types of movements. Now, in an integrative mathematical model of fixational eye movements, microsaccades and slow movements can be derived from a common set of dynamical rules, despite their behavioral dissimilarity. Thus, two behaviorally distinct movement types can be explained by a more fundamental principle. In summary, new mathematical models go beyond earlier theoretical approaches, since they generate highly specific and experimentally falsifiable predictions. I conclude that mathematical modeling will help to move our field forward, adding new tools of analysis to the broad range of experimental approaches developed in the field.

Symposium - Models of eye movements in reading

Using E-Z reader to simulate eye movements in reading and non-reading tasks

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Non-reading tasks that share some (but not all) of the task demands of reading have often been used to make inferences about how cognition influences when the eyes move during reading. In this article, we use variants of the E-Z Reader model of eye-movement control in reading to simulate several of these tasks, including z-string "reading", target-word search, and visual search of Landolt Cs. These simulations demonstrate that a single computational framework is sufficient to simulate eye movements in both reading and non-reading tasks, but also suggest the existence of task-specific differences in both saccadic targeting (i.e., "decisions" about where to move the eyes) and the coupling between saccadic programming and the movement of attention (i.e., "decisions" about when to move the eyes). These findings together suggest that the eye-mind link is flexible, and can be configured in a manner that supports efficient task performance.

Glenmore: A liquid state machine implementation

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This talk will present an extension to the Glenmore interactive activation model of eye movement control in reading [Reilly & Radach, 2006, *Cognitive Systems Research*, 7, 34-55]. The extension implements a more biologically realistic front-end to the model employing as a building block networks of spiking neurons based on Maass's Liquid State Machine architecture [Maass et al., 2002, *Neural Computation*, 14, 2531-2560]. The aim of the model is to gain a more precise understanding of the low-level dynamics of saccadic eye movement control in reading and of the early stages of letter and word recognition. The model provides a more realistic implementation of the biological mechanisms underlying the saliency construct, a key control feature of the Glenmore model. Moreover, it accounts for the trans-saccadic integration of information across fixations in a more biologically plausible manner than the previous version of the model.

Reading shuffled vs. normal text: A simulation study using the SWIFT model

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In a study of shuffled text reading, Schad, Nuthmann, and Engbert [2010, *Vision Research*, 50(23), 2600-2616] found experimental effects of spatially distributed word processing, replicating previous findings from corpus analyses of normal text. Statistical analyses (GLMM) of eye movements revealed several differences and similarities between tasks. The differences could be parsimoniously explained by a stronger dynamic modulation of the perceptual span by foveal load during reading of shuffled text. Here, we present results from a simulation study using an advanced version of the SWIFT model [Engbert et al., 2005, *Psychological Review*, 112(4), 777-813]. The new version of SWIFT implements a dynamical modulation of the processing span. We demonstrate that SWIFT is a viable model for eye movement control during reading of normal and of shuffled text. A genetic algorithm is used to estimate model parameters for each task. Parameter estimates can be used to test hypotheses about how eye movement control differs between reading tasks. We use this approach to test specific hypotheses about reading of shuffled versus normal text concerning spatially distributed word processing and the dynamical processing span.

A rational model of eye-movement control in reading

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Leading contemporary models of eye movement control in reading [e.g., Reichle et al., 1998, *Psychological Review*, 105, 125-157; Engbert et al., 2005, *Psychological Review*, 112, 777-813] have found considerable success in modeling progressive saccades through text, but less success in three key-and, we argue, related-respects. First, effects of variables like word length, frequency, and predictability are generally not derived directly, but only through exogenous functions governing word "processing rates". Second, these models have no account of word misidentification [e.g., Slattery, 2009, *Journal of Experimental Psychology: Human Perception and Performance*, 35, 1969-1975]. Third, these models have limited ability to account for regressive saccades. Here we describe a rational model of eye movement control in reading that meets these challenges. In this model, readers move their eyes to obtain noisy perceptual input and combine it with probabilistic language knowledge through Bayesian inference to yield gradient posterior beliefs about sentence form and structure. Eye-movement policies optimal with respect to reader goals are found through reinforcement learning. We show that regressive eye movements (compensating for occasional word misidentification) are inevitable because they allow superior average speed/accuracy tradeoffs to be achieved. We also examine the effects of linguistic variables that fall out of this model.

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Language processing and eye-movement models

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Previous work [Boston et al., 2011, *Language and Cognitive Processes*] has shown that surprisal [Hale, 2001, In *Proceedings of NAACL*, 1-8] and retrieval difficulty [Lewis & Vasishth, 2005, *Cognitive Science*, 29, 1-45] are significant predictors of reading time in the Potsdam Sentence Corpus [Kliegl et al., 2006, *Journal of Experimental Psychology: General*, 135(1), 12-35]. It remains an open question how such measures of parsing difficulty interact with eye movement control processes [Reichle et al., 2009, *Psychonomic bulletin & review*, 16(1), 1]. We investigate this interaction within the eye movement control model EMMA [Salvucci, 2001, *Cognitive Systems Research*, 1(4), 201-220], a serial attention shift model similar to EZ-READER [Pollatsek et al., 2006, *Cognitive Psychology*, 52, 1-56], which is integrated in the cognitive architecture ACT-R [Anderson et al., 2004, *Psychological Review*, 111(4), 1036-1060]. We present initial results of a modified version of the EMMA model that incorporates predictions regarding parsing difficulty. In addition we present plans of integrating language processing measures into established eye movement models like EZ-READER and SWIFT [Engbert et al., 2005, *Psychological Review*, 112(4), 777-813].

Bayesian saccade planning during reading: The role of word boundaries

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During reading, readers systematically fail to move their eyes to the center of words if saccades are launched from short or long distances to the target position. This finding is traditionally interpreted as the signature of a range error in the oculomotor system. In contrast, Engbert and Krügel [2010, *Psychological Science*, 21, 366-371] showed that the launch-site effect can be derived from Bayesian decision theory, which solves the problem of optimal computation of target position based on noisy sensory information. Recently, the skipping of an intervening word has been identified as another independent variable with a large impact on within-word landing positions [Krügel & Engbert, 2010, *Vision Research*, 50, 1532-1539]. Here we present an extended Bayesian model for saccade planning, based on the idea that two visual cues, provided by the word boundaries, are used in combination with prior knowledge of the distribution of saccade targets to derive estimates of word-center positions with maximum a-posteriori probability. We demonstrate that the launch-site effect and the effect of word skipping result from the same perceptual processes in saccade planning during reading. Implications for reading theories are discussed.

Symposium -Foveating a moving target: Retinal and extra-retinal processes

Internal representations for acquiring moving targets

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The representation of moving targets in monkey prefrontal cortex was investigated using paradigms in which a visible moving target was rendered invisible for part of its trajectory. The time during which the target was invisible varied from 500 to 1250 msec, and monkeys made saccadic eye movements to the estimated location of the target during this period. The responses of neurons in the frontal eye field (FEF) were modulated by target motion parameters such as speed and direction, and neuronal activity continued to reflect these parameters when the target was invisible. Monkeys often made multiple saccades while the target was invisible. Residual targeting errors after the first saccade tended to be corrected by subsequent saccades even though there was no visual feedback. Corrective saccades are evidence of an internally generated error signal. Neuronal activity in the frontal eye field was directionally tuned before both primary and secondary saccades. Separate subpopulations of cells encoded either saccade direction or direction error before the second saccade. These results suggest that FEF neurons encode the error after the first saccade, as well as the direction of the second saccade. Hence, FEF appears to contribute to detecting and correcting movement errors based on internally generated signals.

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Tracking an invisible target requires prediction and internal models

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In order to grasp an object in their visual field, humans orient their visual axis to targets of interest. The appearance of a moving stimulus in the environment elicits smooth pursuit eye movements with a latency of around 100ms. Given this delay, the oculomotor system needs to develop strategies to avoid the buildup of position error during tracking of a moving target. For instance, the oculomotor system uses prediction to anticipate the future target trajectory. Here, we will show that this predictive pursuit response is based on a dynamic internal representation of target motion, i.e. a representation that evolves with time. In addition, our frontotemporal lobar degeneration patient study indicates that this representation can be altered. Despite this internal representation, the smooth pursuit gain decreases after the disappearance of a target, leading to a buildup of position error. The accurate compensation of this position error by saccades suggests that the output of the smooth pursuit forward model is available to the saccadic system. In summary, predictive pursuit and saccades achieve a common goal during target occlusion: they ensure an optimal perception of the target at reappearance.

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Saccadic foveation of a moving target without and with a spatiotemporal perturbation

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When generating a saccade toward a moving target, the target displacement that occurs during the period spanning from the time of target detection to the time when the saccade stops represents a spatio-temporal challenge for the brain. Two studies were performed in monkeys to understand how the nervous system can produce such an efficient response. The first one consisted of testing saccades toward a moving target with a behavioral approach that allowed isolating the influence of visual motion signals on saccades. The results provide a new interpretation of the dynamics of saccades toward a moving target. The second experiment consisted of testing the visuo-saccadic system under perturbed conditions. An unexpected change in eye position was induced by an electrical microstimulation in the deep Superior Colliculus while the monkey was preparing to orient its gaze toward a moving target. The results show a compensatory mechanism when the direction of evoked saccades was opposite to target motion. However, variability in the compensation was found when the direction of the electrically evoked saccade was ipsilateral to the target motion direction. More fundamentally, evidence will be shown demonstrating a spatiotemporal elasticity in the brain for orienting the gaze toward a moving target.

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Causality attribution biases oculomotor responses

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When viewing one object move after being struck by another, humans perceive that the action of the first object "caused" the motion of the second. It is not yet known whether the notion of causality exists as a fundamental, preattentive "Gestalt" that can influence predictive motor processes. Eye movements of human observers were measured while viewing a display in which a launcher impacted a tool to trigger the motion of a second "reaction" target. The reaction target could move either in the direction predicted by transfer of momentum after the collision ("causal") or in a different direction ("noncausal"), with equal probability. Control trials were also performed with identical target motion, either with a 100 ms time delay between the collision and reactive motion, or without the interposed tool. Subjects made significantly more predictive movements (smooth pursuit and saccades) in the causal direction during standard trials, and smooth pursuit latencies were also shorter overall. These trends were reduced or absent in control trials. In addition, pursuit latencies in the noncausal direction were longer during standard trials than during control trials. The results show that causal context has a strong influence on predictive movements.

Motion integration for pursuit: Adaptive mixing of visual and predictive signals

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Visual uncertainties such as the aperture problem introduce biases in smooth pursuit, as evidence when tracking a translating tilted bar. A dynamic solution for reducing this tracking error is a recurrent Bayesian network [Bogadhi et al., 2011, *Vision Research*, 51(8), 867-880]. Such framework can be extended to understand interactions between sensory and predictive signals. We will review a series of experiments probing the role, or absence of, predictive signals when computing the trajectories of the target to be pursued. First, we showed that predictive signals can trigger anticipatory responses in the correct direction but cannot prevent the initial bias when the target starts to move [Montagnini et al., 2006, *Journal of Neurophysiology*, 96, 3545-3550]. Second, perturbation in motion information through short duration blanks at different times (initial and steady state) during pursuit suggests that the system employs a different adaptive mixing of retinal and extra-retinal signals at different stages of pursuit. In the same vein, an abrupt change in target orientation during steady-state tracking cannot be overcome by predictive signals. On the opposite, a smooth change in target orientation is filtered out, thanks to target motion prediction. Altogether these results argue for an adaptive interaction between these two types of signals, enabling the pursuit system to both act and react.

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Integration of salience and value information for smooth pursuit eye movements

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We investigated how bottom-up salience and top-down value information interact for the dynamic guidance of smooth pursuit. Our pursuit stimulus consisted of two overlapping random-dot kinematograms (RDK) with opposite contrast polarity, moving in two different directions at various coherence levels. Subjects won points for pursuing one RDK and lost points for pursuing the other RDK. Points were converted into a monetary reward at the end of the experiment. Both salience and value influenced the pursuit direction. Subjects moved more in the direction of the RDK that was more coherent and rewarded. However, the relative contributions of salience and reward changed over time. In the early phase of pursuit, subjects followed a salience-weighted average direction. Later pursuit, after about 450 ms, followed the rewarded direction exclusively. Our results show that salience and value information is dynamically integrated for smooth pursuit. The integration of the top-down value information seems to be time-consuming since it is not present in the early phase of pursuit. This integration process seems to be slower for the pursuit of moving stimuli than what we had previously observed for saccadic eye movements to stationary stimuli.

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Scenes II: Bottom-up & Top-down processes

Influence of sound on visual gaze when looking at videos

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We propose an analysis of the effect of sound on visual gaze when looking at videos. An audio-visual experiment was designed where participants were asked to look at short video excerpts, without any specific task. To test the effect of sound, fifteen participants completed the experiment in an audio-visual condition and fifteen participants in a visual condition. Sixty video excerpts (a total of about 10900 frames) lasting 5-8 seconds were selected from films that were interesting for both visual and audio. During the experiment, human eye position was tracked by an Eyetracker Eyelink II (SR Research). (i) We classified the sound in three classes: on-screen speech, non-speech and non-sound. We observed with statistical methods that the effect of sound is different depending on the class of sound. (ii) Then a comparison of the experimental data and a visual saliency model was carried out. The results showed that adding sound to video decreased the predictability of the visual saliency model without a sound pathway. (iii) Finally, we created a "sound localization pathway" by locating the coordinates of the sound source on each image manually. In this case, the prediction was better for participants in the audio-visual condition.

Real and implied motion at the center of gaze during natural viewing

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Perceiving and responding to movement is essential for the survival of our species. Still, most studies of natural visual attention employ static visual scenes. Here we recorded eye-movements of human subjects viewing very high resolution natural videos and still frames taken from the same videos. In addition to static visual features such as luminance contrast, we investigate the saliency of dynamic features, namely motion-energy contrast and motion-directed contrast. We show that dynamic features are better predictors of fixation location than static ones, even though the values are of similar orders of magnitude. Nevertheless, across stimuli, the variability of dynamic feature saliency is higher than the variability of static feature saliency. Moreover, around half of the effect size for dynamic features is explained by implied motion, since in still frames people fixate regions that contain movement in the corresponding videos. The dynamic features are highest around 40 ms (duration of a single frame) prior to the fixation onset, suggesting a temporal window for the operation of attentional mechanisms. The present results not only show a strong relationship between dynamic features and fixation selection, but also demonstrate that the contributions from real and implied motion can be investigated separately.

Bottom-up is going down: Oculomotor evidence for top-down control following the initial saccade

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There exists an ongoing debate regarding the extent to which vision is guided by automatic stimulus-driven or volitional goal-driven processes. The present study attempts to resolve this issue by investigating the time-course of both processes over multiple eye movements. Observers were presented with a display containing three differently salient orientation singletons embedded in a homogeneous background of lines. Eye movements were recorded while observers searched for a target superimposed upon one of the singletons or for a specific singleton identity. To explore the time-course of salience-driven and goal-driven processes, eye movements were analyzed as a function of saccadic latency. Initial saccades elicited shortly after the onset of the search display were primarily salience-driven whereas those elicited after approximately 250ms and second saccades were unaffected by salience. In contrast, initial saccades were increasingly under top-down control with longer latencies, and were consistently goal-driven during second saccades, irrespective of latency. This suggests that the extent to which vision is guided by stimulus-driven or goal-driven processes depends on the absolute amount of time passed between stimulus onset and the initiation of a saccade, with salience being represented in the visual system only briefly after an image enters the brain and being ineffective thereafter.

Optimal search: Combining expectations and visual information

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Has evolution provided us with the ability to conduct optimal search? We consider a key prediction arising from Bayesian optimal search: whether human searchers combine prior expectations with visual observations optimally. Bayesian optimal search predicts that observers infer the location of a target by combining (a) all visual evidence of a target being in each location (the likelihood) and (b) the (prior) expectation of a target at that location. Spatial expectation was manipulated using peripheral pre-cues with varying validities. Observers were forewarned of the pre-cue validity in each experimental block. Following the cue, a search array was displayed comprising a peripheral Gabor target amongst distractors. Humans behave near optimally when combining spatial expectations from the pre-cue and visual information from the search array. Initial orienting to the cued location varies systematically with cue validity, but not slavishly: the cue does not elicit as many fixations on invalid cue trials. There are limitations to optimality however: short-latency saccades show oculomotor capture, even when the cue has 0% validity. Our data suggest that the search task may be underpinned by a spatial representation that combines expectation and observations, akin to a priority map.

Scanpaths are planned ahead in visual search

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In visual search, eye movements are often required to locate a target. During search, observers generally select elements resembling the target (potential targets) and ignore those that do not. The consecutive selection of these potential targets forms a path. In a non-search task it has been demonstrated that such scanpaths can be planned ahead as a whole [Zingale & Kowler, 1987, *Vision Research*, 27(8), 1327-1341]. However, it is not yet known whether this applies to visual search. Here we ask to what extent scanpaths are preprogrammed in visual search. We tested this, using displays containing both elements that resemble the target and elements that do not. We find that the ability to deviate from planned paths depends on the properties of the target and the distractors (Experiment 1). Furthermore, we provide evidence that planned paths can include at least three saccades (Experiment 2). These findings show that scanpaths are preprogrammed in visual search. Deviating from a preprogrammed path is possible, but at the cost of longer latencies.

Eye movements of experts and champions in a high-speed sensorimotor task in the dark: Evidence for LTM driven saccades

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Humans perform on average 3 - 4 saccadic eye movements per second. These eye movements are normally driven by scene knowledge and the current task. For automatized sensorimotor tasks, reproducible sequences of saccades, so-called scanpaths, can be observed. During imagery, dreaming, memory retrieval and other simulation tasks these scanpaths are content-related, although the corresponding visual input is unavailable. We investigated how scanpaths look like when an automatized sensorimotor task is performed in complete darkness. The bimanual, high-speed motor task required grasping, moving, rotating, and putting down objects. Eye movements of well-practiced experts, the European champion, and the World champion were recorded and compared between normal vision and darkness. All participants revealed lower rates and longer durations of fixations in the dark, whereas scanpaths and eye-hand time dynamics were highly similar. Yet, scanpaths similarity was not related to task performance. However, champions in contrast to experts did perform comparably fast during normal vision and in the darkness. Based on these results, we argue that eye movement control in automatized sensorimotor tasks relies heavily on long-term memory information. In addition, visual information becomes progressively less important with expertise and performance of international champions seems not to presuppose the availability of visual information.

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Symposium - Vergence eye movements: Brain function and plasticity

The interaction of vergence with saccades and the translational VOR

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Whenever gaze shifts or relative viewer-target motion includes a depth component, disconjugate eye movements are needed for stereopsis. Binocular viewing during fore/aft subject or target translations imposes complex geometrical requirements that depend dramatically upon the eccentricity of the object of interest with respect to the eyes. In a first study we investigated the early response to fore/aft translational movements of the subject or of the target using small (≈ 3 cm) abrupt (0.7g) translations in four normal subjects while viewing a near target being either centered between the eyes, aligned with the right eye, or to the right of the right eye. The mean translation profile computed for each subject was then used to drive a visual stimulus across the same distances and in the same eccentricities used during translations. Visually and vestibularly driven responses were dynamically different but always appropriate in terms of monocular direction and of their disconjugacy. In a second experiment we studied gaze shifts between two targets aligned either on the sagittal plane or on one eye lying at 20 and 200 cm from the frontal plane through the subject's eyes. A functionally inappropriate, conjugate component of saccades was instead always present in these conditions.

Error correction in vergence eye movements

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In vergence eye movements, the fast components of the response, sometimes referred to as vergence saccades, quickly bring the eyes close to the desired position. However, like saccades, there is usually a small error that remains after the movement. Given that the final vergence error, termed fixation disparity, is very small, some highly effective corrective mechanism(s) must be evoked during the late vergence response. In the saccadic system, corrections are made either by secondary saccades or smooth pursuit, but the corrective mechanism in vergence is unknown. Since the residual error can be conjunctive and/or disjunctive, possible corrective mechanisms include: small saccades, smooth pursuit, symmetrical vergence, or a combination of these movements. It is also possible that some type of asymmetrical vergence or uniocular eye movement is used to achieve the highly precise final fixation. Previous work has indicated that a combination of saccades and vergence is used to correct large fast vergence errors and that the dominant mechanism is subject dependent. Here we analyze the late component of the ocular response to a step change in pure (i.e., symmetrical) vergence and demonstrate that fine correction is the product of closely coordinated conjunctive and disjunctive slow components.

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Vergence and binocular eye movements during REM sleep

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Binocular control and vergence eye movements to visible objects have been subject to numerous studies. But what happens if visual information is occluded? We studied vergence during blinks (short term occlusion) and binocular control during REM sleep (long term occlusion). Effects of blinks on slow vergence eye movements were studied by trigeminal stimulation (air-puff) which elicited a fast convergence followed by a divergence component. Interestingly, divergence was in opposite direction to stimulus movements. Furthermore we studied eye movements in REM sleep in six subjects by scleral search coils. Sleep EEG was recorded simultaneously by a recording system which can be used in magnetic fields. Sleep stages were scored online; right within the third REM sleep phase we inserted a scleral search coil in each eye with a subsequent sleep period of two hours. Data show that the eyes move mainly conjugated during fast phases of REMs but may diverge in the roving phases vertically and horizontally. These results suggest that the fixation control system is dimmed during sleep whereas burst cells in the midbrain stay awake.

Presbyopia: Impact on vergence capabilities and binocular strategy

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Presbyopia has a major impact on binocular function. Physiological loss of accommodation may induce reduction of vergence capabilities, especially at near vision. Previous works assumed that central suppression allowed presbyopic patients to prevent troubles due to binocular disorders. To test this hypothesis, we studied the frequency and the characteristics of suppression over 68 subjects without any strabismus. According to the results, suppression affected 81% of the sample and didn't depend on age whereas subjects who presented binocular symptoms were more concerned by the phenomenon. Furthermore, we noticed that the oldest subjects have a larger size of scotoma and we found a strong connection between fixation disparity and suppression. Finally we pointed out that the main binocular criteria were stronger for subjects who did not exhibit suppression. These data suggest that central suppression could be a binocular strategy for presbyopes to avoid symptoms caused by binocular imbalance during Presbyopia.

Neuroplasticity: Vergence-saccade interactions in dyslexia and tinnitus

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The ability to stabilize the vergence angle during and after saccades develops slowly with age, reaching optimal adult levels at 12 years old. Improvement is based on cerebellar neuroplasticity. I will report an eye movement study which was conducted alongside dyslexic children (11.7ys) while they were made to read or scan letter strings. Relative to aged-matched controls, we measured increased vergence errors at the end of a given saccade and upon subsequent fixation for both tasks. Errors were greater for the proximal condition--i.e., when the subjects read with their eyes converging at 40 cm relative to 100 cm. Moreover, considerable variability in vergence errors and in fixation disparity occurred for dyslexics such that their errors at the end of the saccade and at the end of the fixation were uncorrelated. Thus, dyslexics are confronted with unstable binocular fixation placing more demand on sensory effort. In addition, I will report data from adults with somatic tinnitus--hearing sound in the absence of a recordable internally or externally generated sound. Relative to controls, we measured a slower vergence trajectory, lower accuracy and no acceleration of the vergence by the saccade for combined movements in 3D space. Perhaps tinnitus and vergence-saccade problems are manifestations of mild cerebellar syndrome affecting neuroplasticity, and thus leading to aberrant intra and cross-modal interactions.

Vergence Neuroplasticity - fMRI studies

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The brain is capable of adaptation elicited through neuroplasticity. We studied subjects with convergence insufficiency (CI) as a model to investigate vergence adaptation. This research quantified clinical measurements and functional neural changes associated with 18 hours of vergence training in CI subjects. Vergence step responses were compared between thirteen control and four CI subjects. Clinical parameters were quantified throughout the study and included: near point of convergence (NPC), recovery point of convergence (RPC), positive fusional vergence (PFV), near phoria and eye movements quantified using peak velocity. Neural correlates of the CI subjects were quantified with fMRI. Images were quantified using spatial extent and the average correlation. Independent component analysis (ICA) dissected the vergence eye movement responses to study the underlying magnitude of the transient component. Convergence step peak velocities were significantly slower ($p=0.016$) in CI subjects compared to controls. The CI subjects participating in vergence training exhibited decreases in NPC, RPC and phoria and increases in PFV, average convergence peak velocity, and the amount of functional activity within the frontal areas, cerebellum and brainstem. Using ICA, the transient component magnitude was reduced in CI compared to controls and increased through training. Vergence training may have evoked observed changes.

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Special Symposium in Honor of George W. McConkie – From eye movements in texts and scenes to the perception of a stable visual world

The gaze contingent moving window: Reading, visual search and scene perception

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The gaze-contingent moving window paradigm was introduced by McConkie and Rayner [1975, *Perception & Psychophysics*, 17, 578-586] and generally recognized as providing rather definitive information regarding the size of the effective field of view (or the perceptual span) in reading. Some historical context for the development of the paradigm will be provided, and the basic findings from gaze contingent moving window studies on the perceptual span in reading will be reviewed. The paradigm has also been used more recently to study how much information subjects process on a given fixation in the context of visual search and scene perception. This work will also be briefly reviewed.

Eye movements in scene perception: An exercise in transsaccadic vision

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In 1991 George McConkie spent a sabbatical year at our lab in Leuven and introduced us to the mysteries of change blindness across saccades. 20 years later, intrasaccadic stimulus manipulation has become a powerful tool to unravel the contents and development of the mental representation maintained by viewers as they explore the visual world. We have employed the paradigm to study single object representation, biological motion, perceptual grouping processes and complex scene perception. In the present contribution, we focus on the latter topic. More specifically, we outline how models of scene perception have evolved away from accounts based on single-fixation processing of schematic and fleeting tachistoscopic snapshots. Instead, scene perception now emerges as a multiple-fixation process in which a scene representation is developed across a series of eye movements in as much detail as is required by the task at hand. So it seems, that in pointing out the apparent transsaccadic blindness of scene exploration, George McConkie has actually provided us with the necessary tools and incentive to fully demonstrate the potential richness of transsaccadic vision.

Eye movements in categorical visual search

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Targets in everyday search tasks are typically categories of objects (chairs, trash bins); rarely do we have the luxury of a specific target preview. Whereas search is clearly guided when targets are defined by preview, is search also guided to categorically-defined targets? We address this question from both behavioral and computational perspectives. Behaviorally, subjects searched through random objects for either previewed or categorical targets. Guidance was quantified by the proportion of trials in which the target was the first fixated object. Although guidance was strongest for previewed targets (a picture of an orange), we also found above chance guidance to categorical targets, with better guidance for precisely-cued targets (the word "orange") than for abstractly-cued targets ("fruit"). To understand the process of categorical guidance we borrowed features and machine learning techniques from computer vision to train teddy bear and butterfly classifiers. Using these classifiers we were able to decode categorical search targets (teddy bears or butterflies) based on the objects fixated on target absent trials—essentially using eye movements to read a person's mind. These findings not only suggest that categorical search is guided, but that this guidance is based on visual features defining the target category.

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How do Chinese readers send their eyes to words?

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Current reading models of eye movement control usually take the word as the processing unit without additional considerations. Different from most alphabetic languages with words which are clearly separate by spaces, Chinese is composed of characters with no perceptual word boundary information available in sentences. Moreover, although most Chinese words are compounds, the relationship of a Chinese word to its constituent characters regarding both orthographical and morphological structures, is often not apparent. In consequence, the perceptual and lexical ambiguities need to be solved in order to correctly extract words from the character string. This talk will present how the special characteristics of the Chinese writing system influence eye movement control in reading, addressing the issues of the decisions about which word to land on and where to land in a word. The effects of word predictability and word frequency were examined on fixation duration, fixation probability, and landing position in a word for both adult and young readers. The results suggest Chinese readers make use of the contextual information to resolve the perceptual and lexical ambiguities of words. The contribution of word processing and contextual constraints to eye guidance when reading Chinese is discussed.

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Eye movement control in non-Western writing systems: Testing the “McConkie laws” for Chinese and Thai

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The seminal paper by McConkie et al. [1988, *Vision Research*, 28(10), 1107-1118] on the distribution of landing sites on words by readers of English provided an important empirical and mathematical foundation for a generation of reading models. The findings offered compelling evidence that readers' effective target is the word centre. The ability to attain this target is perturbed by factors such as launch distance from the target and noise in the eye-movement control system. An open question is the degree to which the systematic pattern of landings found for English also pertain to non-Western writing systems and especially those not explicitly delimiting words such as Chinese and Thai, with Korean occupying a midway position. This talk will describe a variety of corpus and experimental studies from the perspective of McConkie's word-targeting principles. The evidence suggests that readers in all writing systems demonstrate a tendency to aim for word centres and a clear saccade distance effect, even when the word is not clearly delimited. It appears that the landing distributions are gaussian in shape, though flatter than those found for spaced writing. Moreover, readers of unspaced writing systems appear able to use the statistics of characters occurring at word boundaries to modulate their landing sites.

The “When” decision: How the brain decides whether and when to initiate a planned saccade in reading

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Saccade latency in reading reflects both ocular strategies and difficulties in text processing. McConkie and colleagues quantitatively described the decision of saccade initiation as composed of two main sub processes, with the effect of text process on saccade initiation characterized as a constant delay to a variable amount of planned saccades dependent on the occurring timing of such effect. How does the brain appreciate the need to delay saccade initiation in accordance with difficulties in text processing? A series of electrophysiological studies were conducted to elucidate cortical control of saccade initiation. In them, microstimulation was applied to the supplementary eye field ipsilateral to the direction of a planned saccade. Saccades were delayed for a constant time and the proportion of saccades being delayed depends on the proximity of stimulation onset in relation to saccade initiation time. Temporarily disabling the ipsilateral SEF results in the inability to delay planned saccades. Based on these findings, a dual-control model of saccade initiation time in reading is proposed in which saccades are triggered at a time determined by subcortical signals, which results from a transfer of learning in motor control, and a cortical withhold signal that can supersede the pre-programmed signal probabilistically.

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To aim or not to aim, that is the question: A novel, no-saccade-target theory of eye guidance in reading

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One of G. McConkie's main research questions was whether the saccadic movements of our eyes in a text or a scene are aimed at specific target locations in peripherally-selected words/objects. This issue remains unresolved today, but the majority of models of eye-movement control in reading maintains the assumption that saccades are goal-directed movements aimed at the centre of words of interest, and only sometimes subject to whims of the oculomotor system. Yang and McConkie [2004, *The European Journal of Cognitive Psychology*, 16(1/2), 226-261] argued against this view after showing that visual and lexical information intake is extremely slow and can only modulate a default, dumb move-forward strategy. Here, I will propose an alternative no-saccade target view of eye guidance in reading. This relies on one simple and robust phenomenon, the global effect (or saccade averaging), which reflects dynamic reshaping of neuronal activity in the motor map of the Superior Colliculus. I will argue that where the eyes move on the line of text is mainly determined by the visual configuration formed by letters and words and lateral interactions between the corresponding peaks of neuronal activity in the motor map.

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Symposium - Look away: Cognitive control of saccades investigated with the anti-saccade task

The modulatory effects of context on antisaccade performance

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Antisaccades are attentionally demanding and generate less neural activity than prosaccades in ocular motor structures, factors that may facilitate the emergence of modulatory effects. We describe four effects we have studied recently. First, distractor-induced deviation of saccadic trajectories are greater for antisaccades than for prosaccades, consistent with spatial interactions between distractors and targets in neural structures. Second, antisaccades similarly show a greater 'global effect', once corrected for latency differences. In this study, antisaccades were also used to show that the global effect originates in spatial averaging with computations of the saccade goal rather than stimulus localization. Third, we described a new phenomenon seen in antisaccades but not prosaccades: in 'alternate goal bias', saccades are slightly deviated towards the location of alternative goals used in the same block of trials, an effect which stems partly from recent history and partly from expectations about the immediate future. Finally, we studied reward modulation, and found that both prosaccades and antisaccades showed the same general gains in efficiency and selective action-value effects. A future challenge is to understand the neural differences between effects that are enhanced for antisaccades over prosaccades and those that are equivalent for the two.

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A functional and structural investigation of the human fronto-basal volitional saccade network

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In monkeys, parallel loops from the cortex to the subcortical basal ganglia (BG) exert volitional control over automatic behavior. We investigated the functional and structural organization of the human cortico-basal oculomotor network using high resolution fMRI and diffusion tensor imaging (DTI). Participants performed saccades in darkness, pro- and antisaccades and observed stimuli during fixation. The human frontal eye fields (FEF) along the precentral sulcus revealed lateral motor zones, a slightly more fronto-medial zone selectively active for ipsilateral antisaccades, and a visual zone throughout the anterior FEF. The supplementary eye fields (SEF) were identified along the medial wall containing all three aforementioned functions. In the striatum, receiving the vast majority of BG input, almost all saccade related activation was observed in the putamen, previously considered a skeletomotor striatal subdivision. Putamen antisaccade activation preceded prosaccade activation. Activation specifically evoked by the antisaccade cue was clearest in the FEF and putamen, perhaps presetting the system for volitional actions. DTI fiber tracking revealed that the FEF zones were mainly connected to the putamen, in agreement with the fMRI findings. We conclude that the human FEF contains functional subdivisions comparable to non-human primates, whereas connections to and activation in the BG seem fundamentally different.

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Relation between antisaccade performance, brain function and brain structure from late childhood to adulthood

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The antisaccade task (suppress the prepotent, reflexive, prosaccade to a peripheral visual stimulus and instead initiate a voluntary saccade to an opposite position) is used extensively to investigate cognitive control over behavior. Antisaccade performance gradually improves from infancy to adulthood: reaction times become shorter and the number of saccades made erroneously to the stimulus decreases. Concurrently to these age-related behavioral changes, the brain continues to undergo changes in structure and connectivity. In particular, synaptic pruning and myelination continue into adolescence, along with cortico-subcortical connectivity supporting cognitive control over behavior. Because antisaccade generation relies on an extended brain network (e.g., frontal, parietal and visual cortical areas, striatum), the maturational changes in brain structure may influence brain activity in the antisaccade network that may in turn impact behavioral performance. The goal of our work is to examine this brain-behavior interplay. Here, we will present our study combining eye movement recording, functional magnetic resonance imaging (fMRI) and structural imaging in participants from 8 to 25 years-old while they performed antisaccade and prosaccade tasks. We will show to what extent neural activity and cortical gray matter thickness in the antisaccade network contribute to better control over saccade initiation and suppression as ages increases.

Genetic and neuroimaging studies of antisaccades in the schizophrenia spectrum

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Schizophrenia is a severe psychiatric condition known to be associated with cognitive deficits. The antisaccade task has been used extensively in schizophrenia research, mainly for three reasons, namely to study (1) aspects of cognitive dysfunction, (2) the neural pathophysiology, and (3) the genetics of this condition. In this talk I will first give a brief overview over the key findings from antisaccade research in the schizophrenia spectrum. Here I will focus not only on work with schizophrenia patients but will also discuss findings from high-risk populations such as the patients' unaffected first-degree relatives and schizotypal individuals, two populations who also show antisaccade impairments. I will present new data from neuroimaging studies on the neural mechanisms of such deficits in schizotypal individuals. Finally I will present evidence from genetic studies which are beginning to delineate the molecular mechanisms that may underlie individual differences in antisaccade performance.

Ulrich Ettinger is supported by a DFG Emmy Noether Grant (ET 31/2-1).

Error monitoring potentiation by low dose NMDA antagonist ketamine

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Humans and monkeys adjust their behaviors adaptively, responding slower after erroneous actions as compared to correct ones. The neurophysiological substrates of this adaptation are unknown, but recent work has suggested that the NMDA receptor may play a crucial role. In particular NMDA appears to modify decision-making in perceptual discrimination of macaques and restore motivation in patients with treatment-resistant depression. To further explore this role, we administered an intramuscular injection of noncompetitive NMDA antagonist ketamine while macaque monkeys were performing a pro-anti saccade task. We found that low dose ketamine improves monkeys' performance to adapt to a change in motor plan. In particular, systematic post error adjustment was potentiated by low dose injection of ketamine. This result provides surprising new insights into the neural mechanisms through which executive control is exerted.

Prefrontal cortex deactivation in macaques alters activity in the superior colliculus and impairs control of saccades

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The cognitive control of action requires both the suppression of automatic responses to sudden stimuli and the generation of behaviour specified by abstract instructions. Though patient, functional imaging, and neurophysiological studies have implicated the dorsolateral prefrontal cortex (dlPFC) in these abilities, the mechanism by which the dlPFC exerts this control remains unknown. Here we examined the functional interaction of the dlPFC with the saccade circuitry by deactivating area 46 of the dlPFC and measuring its effects on the activity of single superior colliculus (SC) neurons in monkeys performing a cognitive saccade task. Deactivation of the dlPFC reduced preparatory activity and increased stimulus-related activity in these neurons. These changes in neural activity were accompanied by marked decreases in task performance as evidenced by longer reaction times and more task errors. The results suggest that the dlPFC participates in the cognitive control of gaze by suppressing stimulus-evoked automatic saccade programs.

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Orienting Response I

Quantification of visually-guided orienting responses to visual stimuli with differences in saliency

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Recent insights state that different visual processing streams contribute to the build-up of an internal saliency map. This map represents the most conspicuous area in a visual scene. It is considered the motor for selective shifts in visual attention and initiation of orienting eye movements. We hypothesized, that the presence or absence of orienting eye movements in response to a particular visual stimulus may be a quantitative method to study visual information processing. We quantified orienting behaviour in terms of reaction time and fixation accuracy using remote eye tracking (T60XL, Tobii, Sweden). A variety of stimuli which differed in saliency were subsequently presented to a control group of 213 children and a group of 30 children suspected of Cerebral Visual Impairment (CVI), all between 0-14 years. In the controls, development of orienting behaviour was age dependent: reaction times to the most salient stimulus were significantly prolonged during the first two years in life. Increasing reaction times correlated with decreasing saliency. In CVI patients, we found prolonged reaction times compared to controls. No correlation was found between reaction times and saliency. We propose that CVI patients may have impairments in integrating visual features (motion, color, contrast) that delay orienting responses.

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Cerebellar activations related to saccadic inaccuracies

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Using functional MRI we assessed the activity in the human cerebellum related to the properties of post-saccadic visual errors that drive the plasticity of saccadic eye movements. In the scanner subjects executed blocks of saccadic eye movements toward a target that could be randomly displaced during the saccade, inducing a random post-saccadic visual error. The intra-saccadic shift was randomly forward or backward, and could be either small or large. Post-saccadic visual errors induced activation in several cerebellar areas. These areas included, but were not limited to, the oculomotor vermis which is known for its role in saccadic control. Large errors yielded more activation in the cerebellar hemispheres, whereas small errors induced more activation in the vermis. Forward shifts induced more activation than backward shifts. Our results suggest that the differences in cerebellar activation patterns for different sizes and directions of post-saccadic errors could underly the behavioral differences observed between various saccadic adaptation paradigms. In addition, the outcome argues for an extended range of cerebellar target areas in electrophysiological studies on saccadic eye movement control.

A unified theory of saccadic adaptation and variability suppression based on cerebellar motor learning

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Saccades show endpoint and trajectory variability even when made repetitively to the same target, and random noise in motor commands and visual uncertainty of target localization seem to degrade accuracy. Cerebellar lesioning can greatly increase the endpoint variability of saccades, and also deprive the saccade system of its ability for rapid adaptation with the double-step paradigm. Since motor noise seems to occur in the upper stream during command generation, feedback control may be ineffective in adjusting the trajectory. Furthermore, even if the rapid adaptation could be completed in a single trial, the reduced (or increased) gain would make a saccade more hypometric (or hypermetric) for a subsequent undersized (or oversized) command. Thus, rapid adaptation alone cannot explain the reduction of variability. This severe challenge to the traditional concepts of cerebellar function can be resolved if the cerebellum encodes noisy input variation as an internal differential representation and combines it with a motor performance result. Motor learning derived from such a causal relationship could perform adaptation and also cancel endpoint and trajectory variability. To implement this function, I propose a novel preprocessing step performed by a system comprising Golgi and granule cells that endows the cortex with a universal learning ability.

Saccadic adaptation alters the attentional field

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Previous studies have used perceptual performance tasks to show that adaptation of saccadic eye movements affects the pre-saccadic locus of visual attention. Furthermore, a recent investigation (Garaas & Pomplun, JOV 2011) has shown that the metrics of visual-perceptual space were distorted after anisotropic whole-field saccadic adaptation. In the current study, we investigated whether the visual-attentional field, that is, the distribution of attention around fixation, was distorted after adaptation as well. This test was done using the single target saccadic adaptation paradigm and a discrimination task, administered before and after adaptation, in which the participants discriminated between an E or F in a flanker paradigm. Results show that even when eye movements were not allowed, attentional fields shrank or expanded along the axis of backward or forward adaptation, respectively, as demonstrated through interference from distractors at different eccentricities. This finding suggests that modification of saccadic amplitudes not only affects metrics of visual-perceptual space, i.e., object size perception, but the attentional fields associated with the perceptual space as well. The implications of our study are that the neural mechanisms underlying eye movements and spatial attention and perception may be closely linked and be used to continuously recalibrate each other.

The relationship between antisaccade performance and pupil size

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Modern eye trackers continuously record pupil size as well as gaze position. Previous research has shown that pupil size increases as a function of mental effort or cognitive load, although these concepts are poorly defined. Using a very large database of antisaccade trials we explored the relationship between pupil size prior to the fixation offset and standard antisaccade metrics including trial outcome (correct vs incorrect), primary saccade latency, amplitude and velocity. In order to avoid confounds, pupil size values were only included in the analysis if they occurred during a fixation within 0.5 degrees of the screen centre, and in trials without blinks. Data were analysed using hierarchical linear models. Maximum pupil size was significantly larger during the fixation period of trials in which participants went on to make errors compared to trials in which a correct antisaccade was made. Importantly, maximum pupil size during the fixation period of trial N was also related to the outcome (correct vs error) of trial N-1. This result suggests that in standard antisaccade tasks, pupil size on trial N may also reflect processes involved in error detection (conscious or not) and reflect trial-to-trial dependencies that have previously been documented during the antisaccade task.

Microstimulation of the primate superior colliculus induces pupil dilation without evoking saccades

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The orienting reflex is initiated by a salient stimulus to prepare the body for quick, appropriate action. It involves a rapid shift of the eyes, head, body, and attention, and other physiological responses such as changes in heart rate and pupil dynamics. The superior colliculus (SC) is a critical structure in the brain network that coordinates orienting behaviors, particularly gaze shifts, but its causal role in pupil dilation remains poorly understood in mammals. Here, we examined the role of the SC in the control of pupil dynamics. Pupils dilated after a brief presentation of a salient peripheral visual target while monkeys remained fixed, suggesting that pupil dilation is associated with visual saliency. If the SC mediates the orienting reflex, then SC microstimulation should induce similar pupil dilation as evoked by a salient peripheral target. We delivered weak electrical microstimulation to the SC, so that saccades were not evoked. Pupil size increased significantly after microstimulation of the intermediate SC layers. In contrast, microstimulation of the superficial SC layers did not cause pupil dilation. Together, these results suggest that pupil dynamics are associated with visual saliency, and that the intermediate SC is critically involved in controlling pupil dilation as part of the orienting reflex that also leads to shift in gaze and attention.

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Symposium - Interacting with electronic and mobile media: Oculomotor and cognitive effects

Electronic paper vs. LCD: Effects of extended reading on eye movements and visual fatigue

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Most recently light and mobile reading devices with high display resolutions have become popular and they may open new possibilities for education. Based on their display technology two major groups can be distinguished. One type, predominantly found in dedicated e-book readers, uses electronic paper also known as e-Ink. Other devices, mostly multifunction tablet- PC's, are equipped with backlit LCD displays. While it has long been accepted that reading on electronic displays is slow and fatiguing, this new generation is explicitly advertised for reading. Therefore we decided to compare experimentally how these two display types are suited for extended reading. To this end participants read for several hours on either e-Ink or LCD, and different measures of reading behaviour and visual strain were regularly recorded. These dependent measures included subjective (visual) fatigue, a letter search task, reading speed, oculomotor behaviour and the pupillary light reflex. Results suggest that reading on the two display types is good and very similar in terms of both subjective and objective measures. The results are discussed in the light of earlier research and with a view on other properties that may decide over success or failure of e-reading devices in educational use.

Reading from computer displays and dedicated eReaders: Oculomotor and technical aspects

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Two aspects are worth considering in eReading studies. First, the classical parameters of eye movement during text reading: number of fixations, fixation duration, re-fixations. Second, readers' behaviour during interaction with the device. In fact scrolling pages, make annotations, insert bookmarks are basic actions that readers are used to do when dealing with a printed book, but when reading an eBook these actions strongly depend on the level of usability and functionality of the device. The aim of this study is to compare reading eBooks from computer displays and from eReader devices. Different recording equipments have been used according to the experimental set up: remote videooculographic system mounted below the computer display or wearable system that records both eye movements and the visual scene in front of the subject. Leaving the subject completely free to move, the wearable device is the most appropriate when reading from tablets and eReaders. These recording equipments, as many others on the market, provide software applications for data acquisition, data analysis and also make available raw eye movement data. Scanpath analysis provides information useful to investigate behavioural aspects, whereas the analysis of eye movements during reading needs to be performed from a horizontal component of eye displacement.

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Dynamic text and eye movements – challenges of tracking and analysis

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Dynamic text appears sporadically on the screen either based on user's actions or as produced by another user or a news ticker. Dynamic text presentation restricts the researcher from using typical eye movement metrics (fixation count and fixation duration) in the analysis of reading behavior. Specifically, when text appears letter-by-letter, the velocity based fixation algorithm clusters the fixation samples of the succeeding letters that appear continuously on the screen, which produces huge fixations. We tracked eye movements of 20 participants in a print interpreting study using two dynamic text presentation formats, letter-by-letter and word-by-word, at typing speed. We analyzed regressions of eye movements, and found significantly more regressions in the word-by-word format than in the letter-by-letter condition. Over the conditions, paired samples t-test revealed significant difference in the number of regressions starting from the words that end a sentence vs. from other words in the texts. Although letter-by-letter presentation took less concentration and was easier to read, we found almost equal acceptance of both formats. We need special metrics that take into account the variation in the text presentation style to fully understand the underlying cognitive behavior. Only then can we build better tools to support dynamic text presentation.

Functional segmentation of pupil's multimodal task solving: Aligning eye movements and cued retrospective protocols

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Eye tracking methodology has been used to study information processing from multi-representational sources [Holsanova 2010, Norstedts]. Studies show how readers choose entry points and reading paths in printed and digital media and how they integrate text, pictures and graphics [Holmqvist et al. 2003, In Hyönä & Deubel (Eds.), pp.657-670; Holsanova et al., 2006, Visual communication 5 (1), 65-93; Holsanova et al. 2008, Appl. Cognit. Psychol. 23: 1215-1226]. Eye tracking can provide detailed data concerning perceptual and cognitive processes underlying a variety of tasks [Scheiter & van Gog, 2009, Appl. Cognit. Psychol. 23: 1209-1214]. We focus on pupil's interaction with multimodal text book materials and report results from a recent study. We use a combination of eye movements and retrospective verbal protocols to reveal attentional and cognitive processes underlying reading and comprehension of complex materials. One aim is to trace pupils' reading behaviour when solving various tasks in biology and chemistry and to investigate how they integrate information from text, pictures and graphics. Another aim is to uncover pupils' reading strategies and to investigate how these strategies can be used to enhance pupils' learning. During cued retrospective protocols, pupils are shown their own dynamic scanpaths and encouraged to reflect on the process of problem solving. On the basis of both data, we can identify distinct temporal and functional phases in their interaction with the materials.

The use of knowledge awareness tools in computer-supported collaborative learning settings: A dual eye-tracking study

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In the Computer-Supported Collaborative Learning (CSCL) field, there is growing research on group awareness tools (GATs) for learning. GATs are technological tools designed to indirectly guide collaborative learning processes by displaying information about the learning partners (or the group) during the interaction. Knowledge awareness tools are one type of such tools, and provide co-learners with cues about their partners' knowledge. In the present study, university students collaborated remotely in dyads and built a joint concept map on a learning topic. While building the collaborative map, they were able to access visualizations (personal concept maps) of both their own- and their partner's prior knowledge. Two eye-trackers were used to record peers' eye movements during collaboration. Two questions are addressed here: (1) To what extent did co-learners use visualizations of their own- and their partner's knowledge while interacting together? (2) Is there a relation between the amount of time spent consulting the prior knowledge maps and respectively the learning outcomes and the accuracy with which co-learners assess their own- and their partner's outcome knowledge? The result of this study will be presented and the discussion will be extended to address the issue of using dual eye-tracking in CSCL settings.

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Producing and reading annotations on paper documents: A geometrical framework for eye-tracking studies

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The printed textbook remains the primary medium for studying in educational systems. Learners use personal annotation strategies while reading. These practices play an important role in supporting working memory, enhancing recall and influencing attentional processes. To be able to study these cognitive mechanisms we have designed and built a lightweight head mounted eye-tracker. Contrary to many eye trackers that require the readers head to stay still, our system permits complete freedom of movement and thus enables to study reading behaviors as if they were performed in everyday life. To accomplish this task we developed a geometrical framework to determine the localization of the gaze on a flattened document page. The eye tracker embeds a dual camera system which synchronously records the reader's eye movements and the paper document. The framework post-processes these two video streams. Firstly it performs a monocular 3D-tracking of the human eyeball to infer a plausible 3d gaze trajectory. Secondly it applies a feature point based method to recognize the document page and estimate its planar pose robustly. Finally, it disambiguates their relative position optimizing the system parameters. Preliminary tests show that the proposed method is accurate enough to obtain reliable fixations at word level.

Symposium: How does “when” relate to “where” in saccadic decisions?

Are choice and latency dissociable?

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In all current models of saccadic decision, motor plans compete for action, with the activity representing alternative possibilities accumulating towards threshold. When one plan reaches threshold, the decision is made and that plan is executed. At the heart of the first-to-threshold concept is a relationship between choice and speed, because the way an action gets chosen is to cross the threshold earliest. In our talk, we will explain how this fundamental prediction is made by every class of modern computational decision model, no matter what the details of its structure, accumulation or competition processes. Yet this prediction has hardly ever been questioned or tested. If it were disproved empirically, the very concept upon which the models are based, and which makes them attractive, would be undermined. If choice is not necessarily related to speed, then these models might still account for aspects of motor competition, but the choice would have to be primarily determined by a different process. Our talk will address ways to test this prediction and report data that does not appear to support it.

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Skipping benefits and long-range interactions in a sequential scanning task

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During everyday activities, our eyes continuously generate saccades to explore areas of interest. The class of sequential attention shift models suggests that both the decisions a) when to move and b) where to fixate next are tightly coupled to serial processing of objects. Here we study eye movements in a serial scanning task where stimulus n indicates the direction to the next stimulus $n+1$. Our results provide evidence against serial attention shifts as a general theory underlying eye-movement control. First, we observe skipping benefits—the finding that fixation durations are shorter before cases of skipping the next stimulus compared to fixation durations before fixating the next stimulus. Second, target selection is modulated by distant stimuli, however, the same stimuli have no effect on fixation durations. These findings are compatible with the view that parallel processing determines eye movements where multiple targets compete for selection.

Context-selective belief-updating accounts for “noise” in accumulator models of saccadic choice and latency

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Models based on the temporal integration of evidence towards a response threshold successfully account for choice and latency variability of saccadic eye movement decisions. Models typically assume multiple sources of internal noise such as variability in the rate and starting point of accumulation. A major question is where this variability comes from and whether it should indeed be considered noise. The starting point of accumulation is often considered an index of the prior belief that a location will become the target for the next saccade. We present a “front-end” to a simple accumulator model that updates these beliefs in light of recent experience: movement programmes that are consistent with recently executed sequences of saccades are selectively facilitated, but only when the (visual) context matches that in which recent experience was acquired. This model is capable of rapidly learning the statistics of a simple environment in which observers generate short sequences of saccades. Moreover, the statistics of different environments - distinguished by a contextual cue - can be acquired in parallel. Finally, the trial-by-trial fluctuations in expectations derived from recent experience accounts for the variability in starting points and the resulting sequential (i.e. previous trial) effects in eye movement behaviour.

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Gated stochastic accumulator model of visual search

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We describe a multiple-alternative stochastic accumulator model of visual search. Visual neurons in the frontal eye field (FEF) and other sensorimotor areas represent the salience of objects in the visual field. Pre-saccadic FEF and SC movement neurons initiate saccades when discharge rate reaches a fixed threshold. We modeled how the neural representation of salience can determine where and when to shift gaze. We recently showed that a two-accumulator model with firing rates of FEF visually selective neurons as input accounted for response times and FEF movement neuron activity [Purcell et al., 2010, *Psychological Review*, 117(4), 1113-1143]. Here, we extend this approach to a multiple-alternative framework to explain performance and physiology when the set size of the search array varies. Stochastic and systematic variability in the rate of accumulation was given by FEF visual neuron firing rates. Tonic gating inhibition established a criterion that the input must exceed to be accumulated. Models which included gating accounted for choice probabilities and full correct and error response time distributions as well as the dynamics of FEF movement neurons during search. Lateral competitive interactions among accumulating units were necessary to explain search performance, but feed-forward (i.e., diffusion-like) inhibition was not sufficient.

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Neural mechanisms of V1 for initiation of visually-guided saccades

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Psychophysical studies indicate that the visual system relies on sensory evidences in early and brief time epochs for saccadic decision [Ludwig et al., 2005, *J. Neurosci.*, 25(43), 9907-12]. This is corroborated by physiological evidences on the timescale of sensory integration. For the symposium, we will focus on the properties of V1 single neuron activity in relation to the timescale of sensory integration for saccadic initiation. The latency of visually-guided saccade is correlated on a trial-to-trial basis with the first spike time of V1 response, but not with its firing rate [Lee et al., 2010, *J. Neurophysiol.*, 105(5), 2556-2572]. This gives rise to the timescale of sensory integration that outweighs early time epochs with a precision of at least 5ms, substantiating the psychophysically-determined system response. Since V1 firing rate is correlated with saccadic choice [Palmer et al., 2007, *J. Neurosci.*, 27, 8122-8137], it appears that 'when' and 'where' signals for saccadic decision in visual detection tasks can be dissociated at the level of V1.

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The 'when' and 'where' of saccade trajectories: Interactions between visual- and goal-related neuronal signals on saccade deviation in the monkey

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The trajectories of saccadic eye movements are thought to reflect a dynamic interaction between competing visual- and goal-related processes. In humans, saccades have been shown to deviate towards and away from salient non-target stimuli depending on various parameters of the competing signals. However, the neurophysiological basis for this is not well understood. Deviation towards is associated with competition between simultaneously active sites within the intermediate layers of the superior colliculus (SC), a midbrain structure that integrates sensory and goal-related signals for the production of saccades. In contrast, deviation away is hypothesized to reflect a higher-level process, whereby the neural site associated with the distractor is actively suppressed via a form of endogenous, top-down inhibition. We tested this hypothesis by measuring distractor-evoked activation of SC visuomotor neurons while monkeys performed a simple task configured specifically to induce a high degree of saccades that deviate away. While the task produced robust deviation away, we found no evidence of a relationship between saccade deviation in any direction and distractor-evoked activation outside a short peri-saccadic window. This indicates that deviation away cannot be adequately explained by a form of top-down inhibition at the distractor-related locus. The results are discussed in relation to the primary sources of inhibition underlying saccadic control.

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Special Plenary Talk

An initiative for the standardisation of data quality in eye-trackers

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Accuracy, precision, sampling latencies and headbox size are important properties of data quality in eye-movement research. Such properties decide whether the data can be used for a specific purpose or measure, e.g. precision affects the detection of events, while accuracy is important when using AOIs or gaze control. Most commercial technology is subject to international regulations, but there is currently no standard in how to independently measure, calculate and report data quality for eye trackers. Users of eye-trackers almost exclusively reiterate manufacturer claims such as "better than 0.5° accuracy" when reporting data quality, rather than any independently tested standard of quality or even standard means of quality assessment. Alongside uncertainty re validity and comparability of results from different eye trackers, the lack of clarity in methods as well as terminology also means that users or researchers looking for the right product for their needs may incur costly mistakes. COGAIN is taking the initiative to develop an international standard in collaboration with international standardising bodies. This talk will introduce the work being undertaken by the COGAIN technical committee, exemplify current methods of measuring data quality, and introduce the questions remaining for the production of an international standard for eye-movement data quality.

Reading I: Phonology & Speech

The influence of number of syllables on word skipping during reading

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In an eye-tracking experiment during reading, subjects read sentences containing a monosyllabic (e.g. grain) or a disyllabic (e.g. cargo) five-letter word. Target words were matched on frequency, predictability, neighbourhood frequency and bigram frequency. Monosyllabic words were skipped more often than disyllabic words indicating that syllabic structure was extracted from the parafovea early enough to influence the decision of saccade target selection. Fixation times on the target word when it was fixated did not show an influence of number of syllables, demonstrating that number of syllables differentially impacts skipping rates and fixation durations during reading of five-letter words. Implications of this novel finding of very early syllabic structure extraction for current models of eye movements during reading will be discussed.

Stuttering and silent reading: Evidence from eye-tracking studies

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The etiology of stammering is still unclear. Some theories hold that the problem arises at the output stage, reflecting a problem with the motor processes involved in articulation, while others situate the problem at an earlier pre-motor stage, reflecting linguistic failures. Two experiments investigated the differences in the silent reading processes of people who stutter (PWS) and people who do not stutter (PNS) using eye-tracking. Because PWS tend to stutter on longer words, we compared reading times for long and short words in normal sentences across both groups. Experiment 1 showed a much larger length effect for PWS, indicating that they experienced additional processing difficulties for words thought to cause a stuttering event when spoken aloud. Experiment 2 tested whether this effect could be situated at the subvocalisation stage. PWS and PNS read normal sentences either in silence or during articulatory suppression (saying bababa). We again found a disproportionately large length effect for PWS compared to PNS, which was not modulated by articulatory suppression. Together, these findings suggest that stuttering is not (only) a problem at the output (overt vocalisation) level. Implications of this research for theories of reading and language production will be discussed.

Oculomotor and linguistic processing during reading are differentially affected by concurrent working memory load

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Eye-movement control during reading depends on linguistic as well as oculomotor processing. Using a dual task paradigm we demonstrated differential interference by concurrent working memory load. Participants had to encode verbal or spatial item properties for later serial recall in an otherwise visually matched display. Between-task performance was individually adjusted by a span procedure. During each retention interval participants read a sentence. Reading performance was recorded by an eye tracker and compared to two control-conditions without concurrent memory load. As a result, concurrent verbal, but not spatial load, affected word processing, since gaze durations as well as the number of refixations were reduced in the verbal load condition. A further analysis demonstrated that the word-frequency by word-length interaction revealed a reduced word-frequency effect for long words, driven by shorter fixation durations on low frequency words. Hence, verbal working memory load interfered specifically with linguistic processing. In contrast, the distribution of landing positions was not affected by working memory load. This result is compatible with theories claiming that control of landing position is driven mainly by visual processing independently of higher cognitive processing. We conclude that concurrent cognitive load had a clear effect on linguistic but not on oculomotor sentence processing.

Inner speech during silent reading reflects the reader's regional accent

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While reading silently, we often have the subjective experience of inner speech. However, there is currently little empirical evidence as to whether this inner voice resembles our own voice whilst speaking out loud. The current study exploits prosodic differences in regional accents to investigate this issue. Specifically, we compared reading behaviour of Northern and Southern English participants who have differing pronunciations for words like 'glass', in which the vowel duration is short in a Northern accent (rhyming with 'mass') and long in a Southern accent (rhyming with 'sparse'). Participants' eye movements were monitored while they silently read limericks in which the end words of the first two lines (e.g., glass/class) would be pronounced differently by Northern and Southern participants. The final word of the limerick (e.g., mass/sparse) then either did or did not rhyme, depending on the reader's accent. Results showed longer go-past reading times for the final word of the limerick, and more regressions to the end words of lines one and two, when the final word did not rhyme, based on the accent of the reader. This would suggest that inner speech during silent reading resembles the external speech of the individual reader.

What is the eye doing during reading aloud? Eye-voice span analyses in acquired dyslexia

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The investigation of spatial and temporal relationships between eye movements and the simultaneous verbal production during reading aloud is a historical topic in research on eye movements. The relationship between articulation and eye movements is traditionally referred to as eye-voice span (EVS). In recent years the issue has seen a renaissance, with a number of current studies applying state of the art methodology to the interplay of eye and voice in skilled readers [Inhoff et al., 2011, *Journal of Cognitive Psychology*, 23(5), 543-558]. In readers showing acquired dyslexia this span has not been examined in detail until now. However, current findings suggest specific eye movement patterns in acquired dyslexia [Schattka et al., 2010, *Neuropsychologia*, 48, 2959-2973]. The purpose of our study is to investigate the EVS in normal reading as well as in acquired dyslexia. Different reading strategies and monitoring processes in reading errors are of particular interest. Recent results reveal a significantly longer temporal EVS (Mean: 1258 msec; SD: 664 msec) as well as a significantly shorter spatial EVS (Mean: 5.6 letter characters; SD: 2.9) in acquired dyslexia. Moreover, word properties significantly affect the EVS in normal reading as well as in acquired dyslexia. In addition, reading errors lead to an increasing temporal EVS in acquired dyslexia. By contrast, spatial EVS is decreasing in normal reading during reading errors. Critically, analyses of eye movements in relation to reading errors appear to provide a way to better understand monitoring behavior.

Formal literacy modulates language mediated saccadic eye movements

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We investigated if formal literacy modulates the attentional system, particularly eye movements. We present data from two visual world experiments on low literates (N=25, avg. 5 years of education) and high literates (N=25, avg. 15 years of education) Hindi speaking subjects. In experiment one with both semantic and phonological competitors along with unrelated distracters of a target spoken Hindi word, low literates showed almost no attentional shifts towards the phonological competitors where as both groups quickly oriented their attention towards the semantic competitors, confirming earlier findings that phonological activation leading to language mediated attentional shifts may be poor in low literates. Experiment two examined language mediated anticipatory eye movements on gender marked adjectives. The display included a competitor that took the same adjective as the spoken target word and was similar in gender where as the other competitor only took the adjective apart from distracters. Low literates showed delayed attentional shifts towards both competitors whereas high literates immediately shifted their visual attention towards the competitors compared to distracters. This evidence suggests that literacy may also affect morpho-syntactic representations, which in consequence may modulate the attentional system.

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Symposium - Current views and controversies on saccadic adaptation

Interactions between saccadic adaptation and perceptual localization

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Adaptation of saccadic amplitude in the McLaughlin paradigm leads to changes in the localization of visual stimuli. Stimuli that are presented before an adapted saccade are mislocalized in the direction of saccadic adaptation. The amount of mislocalization depends on the similarity between the saccade vector and the stimulus location, on the similarity between the presentation duration of stimulus and of the saccade target, on the direction of adaptation (inward or outward), and on the size and persistence of the post-saccadic visual error. These dependencies show a strong sensory-motor coupling between visual localization and the control of saccades, which might act early in the oculomotor transform at the level of saccade planning. This suggests that oculomotor planning is an integral part of perceptual space representation.

Dissociating exploring and targeting saccades: Evidence from saccadic adaptation

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A growing set of studies on two-saccade sequences have shown that, besides the well-documented targeting saccades, exploring saccades, i.e. saccades which drive the eye within a currently fixated stimulus, constitute a special category of saccades with specific characteristics [e.g. Vergilino-Perez & Findlay, 2006, *Vision Research*, 46(16), 2204-2216]. Indeed, whereas targeting saccades are coded as a function of target position, exploring saccade amplitude is determined by the size of the explored stimulus. Exploring saccades cannot be adapted by the traditional intra-saccadic target step procedure, but can be adapted by using a systematic intra-saccadic size change. Here we show that whereas classical targeting saccade adaptation does not transfer to exploring saccades, the reciprocal transfer (i.e. from exploring to targeting saccades) occurred when targeting saccades aimed for a spatially extended stimulus, but not when they aimed for an isolated target. These results show that, in addition to position errors, size errors can drive adaptation, and confirm that exploring vs. targeting a stimulus leads to two different motor planning modes.

Saccadic plasticity and Cerebellum

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In our daily lives we interact with our environment through accurate movements. The cerebellum is involved in the control of most motor responses, including saccadic eye movements, which are essential for visual perception. Indeed, the accuracy of saccades is preserved throughout life due to adaptation mechanisms that rely upon the cerebellum. It is widely accepted that the medio-posterior cerebellar areas (vermal lobules VI and VII and caudal areas of the fastigial nuclei) are mainly involved in these adaptation mechanisms. We will present a recent Transcranial Magnetic Stimulation study showing that the hemispheric regions of the cerebellum also play an important role in saccadic adaptation. This experiment demonstrates that cerebellar hemispheres are differentially involved in the adaptive lengthening and shortening of saccades. In another study, we tested cerebellar patients in their adaptation of reactive saccades elicited by sudden target presentation, and of voluntary saccades generated while scanning a set of targets. We found specific adaptation deficits for these two saccade categories, with lesions of superior or infero-posterior cerebellum associated respectively with deficits of voluntary and reactive saccades. We conclude that saccadic adaptation is not controlled exclusively by the medio-posterior cerebellum in humans, thus requiring a reappraisal of the current models of saccadic plasticity.

Cerebellar mechanisms guiding the adaptation of eye saccades: Population coding and relation to oculomotor fatigue

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Growing evidence from studies of patients and surgical lesions in animals indicates that the cerebellum is the locus of plastic changes guiding motor adaptation. This is not only true for the adaptation of saccadic eye movements but also for other examples of motor and even perceptual learning. Recent findings about the firing properties of Purkinje cells (PC) in the oculomotor vermis (the cortical area of the cerebellum subserving eye movements) have revealed neural mechanisms in the cerebellum responsible for the observed adaptive changes of eye saccade amplitude. We demonstrate that saccadic adaptation is not guided by changes in discharge rates of single or even subgroups of neurons but that a PC population signal reveals their functional significance relative to normal saccades and also to changes brought about by adaptation. Moreover, because saccadic adaptation requires that a large number of eye saccades be repeated at a fast rate, the observed adaptive changes are necessarily accompanied by effects of fatigue. We discuss how data from patient and lesion studies, changes in eye saccade kinematics and the PC population signal hint that a functional link might exist between saccadic adaptation and the compensation of oculomotor fatigue.

Evidence against re-mapping in the superior colliculus during saccadic adaptation

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The location of motor-related activity in the deeper layers of the superior colliculus (SC) is thought to generate a desired displacement command specifying the amplitude and direction of saccadic eye movements. During saccadic adaptation, the amplitude of saccades can be systematically altered. There has been debate about whether the SC specifies the desired movement to the original target location or whether SC activity is 're-mapped' to specify the vector of the amplitude-altered movement that is observed as adaptation progresses. We investigated this question by recording the activity of saccade-related burst neurons in the SC of head-restrained rhesus monkeys during both backward and forward saccadic adaptation. Our data are inconsistent with the hypothesis that the locus of SC activity changes as adaptation progresses; the location of SC motor-related activity does not appear to be remapped during either forward or backward saccadic adaptation. Signals that lead to changes in the amplitude of saccades must either bypass the SC or interact with the saccadic burst generator downstream from the colliculus.

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Brainstem contributions to saccadic adaptation

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Saccades are controlled via a direct superior colliculus (SC) to brainstem saccadic burst generator (BG) pathway and a side pathway through the nucleus reticularis tegmenti pontis (nrtp), the vermis and caudal fastigial nucleus to the BG. We summarize our studies that assess the contribution of the nrtp and SC to adaptive plasticity. Discharge of nrtp neurons increased with decreases, but not with increases, in gain during adaptation in about half of nrtp neurons (19/34) tested. The increase was added at the beginning of the burst and the movement field changed for all open movement field neurons. For the SC, 35/43 neurons changed their discharge during gain adaptation but the changes were not uniform. Gain changes could be associated with changes in movement field (either actual or desired saccade size) or number of spikes in the burst. Subthreshold (for evoking saccades) electrical stimulation of the SC is an effective stimulus to produce saccade adaptation. The discharge of SC neurons differs for adapted visual and double-step saccades of the same amplitude and direction. Taken together, our results indicate at least a portion of saccade plasticity occurs at or before the SC and, we suggest, that plasticity is most likely a distributed process.

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Faces & Emotions

The eyes avoid angry faces: Evidence from saccadic curvature

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In everyday life, fast identification and processing of threat-related stimuli is of critical importance for survival. Previous studies suggested that threat-related stimuli receive priority in visual selection, presumably through a direct subcortical route between the amygdala and superior colliculus, a structure involved in the generation of saccade eye movements. In the present study we investigated whether threatening information affects saccade trajectories directly. Participants had to make a speeded endogenous saccade up or down to a target location while an irrelevant face presented on one side of fixation was paired with an object presented on the other side. The results showed that saccades curved away from angry faces but not from either neutral or happy faces. This effect was not observed when the face stimuli were inverted, excluding the possibility that the effect was driven by low-level features. We assume that attention is allocated to both irrelevant objects, and that it dwells longer at angry faces relative to neutral and happy faces. Because attention dwells longer at the angry face, more inhibition is necessary to generate an accurate saccade to the target location. Curvature away from angry faces may therefore reflect fast processing of threatening information through the subcortical pathway.

Oculomotor inhibition with emotional stimuli: Evidence from saccadic trajectories

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This study investigated the degree to which the oculomotor system is influenced by higher-level representation of complex visual scenes, in particular their emotional content. To this end, saccade trajectory curvatures [Ludwig & Gilchrist, 2002, *Behavior Research Methods, Instruments, & Computers*, 34(4), 618-624] were used as a measure of the amount of inhibition evoked by a distractor. Single facial distractors - depicting neutral, happy, and angry expression - were presented laterally while participants executed vertical saccades to a neutral target. Saccadic trajectories curved significantly away from all distractors. The trajectory curvature was significantly greater for happy than angry faces. In particular, this difference was found with long but not with short saccade latencies. This result suggests that later in time happy faces induced more competition and therefore required more inhibition than angry faces. This finding also suggests that an emotion effect on curvature was only found with long latencies due to the time-consuming process of emotion encoding. This is in line with previous research showing an effect of emotional distractors on trajectory curvature with negative stimulus onset asynchrony but not with simultaneous presentation of target and distractor [Nummenmaa, Hyönä, & Calvo, 2009, *Journal of Experimental Psychology: Human Perception and Performance*, 35(2), 305-323].

Hormonal modulation of attention to facial expression of emotion and gaze cues

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Research has proposed that attentional orienting to gaze cues might be modulated by emotional expression. A number of factors that might influence this interaction have been suggested, yet whether this might be affected by hormonal fluctuations has not yet been investigated. This study explored whether this interaction is modulated by fluctuations in progesterone level across the menstrual cycle. Female participants were tested on a gaze cueing task in their luteal (N=13) or follicular phase (N=15), when progesterone is high or low, respectively. Participants were presented with angry, disgusted, fearful, happy, and neutral facial expressions with averted gaze; spatially congruent or incongruent with an upcoming target. Although the modulation of the gaze cueing effect by expressions did not differ between the groups, the luteal group were faster to respond to gazing emotional expressions overall, $F(1,26) = 6.77$, $p < .05$, at 200 SOA. Further at 800 SOA the luteal group showed faster latencies to threat related expressions compared to happy and neutral. It is suggested during the luteal phase; when progesterone levels are characteristic of pregnancy, females are hyper-sensitive to emotionally relevant gazing faces, particularly to those associated with threat. This might be an adaptive mechanism to protect foetal development.

Comparison of eye-movement behavior during facial symmetry and attractiveness evaluation

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Face perception is investigated in terms of several subjective judgments. For instance, the bilateral symmetrical configuration possessed by the faces is known to be effective in attractiveness evaluation. In this study, we investigated the eye-movements of 10 subjects in two tasks in which they evaluated the attractiveness and symmetry of the face images using eye-tracker data from SMI iView X RED System (120 Hz). The stimuli consisted of either original or symmetrical versions of the face images in the METU-FaceTwo Database. As expected, viewing behavior varied between tasks and stimulus. Task related orientations occurred: (1) the faces received significantly more fixations ($p < 0.01$) during the symmetry evaluation and (2) a left-hemiface bias was observed for the attractiveness evaluation of the faces. However this bias was reduced for the symmetry evaluation task in which a more symmetric pattern in viewing was observed. As for stimulus driven effects, subjects fixated on the central features (nose, mouth, chin) more often and longer ($p < 0.001$) for the (1) symmetrical faces during the attractiveness evaluation and (2) original faces during symmetry evaluation. These findings indicate differential fixation patterns in subjective (attractiveness) versus objective (symmetry) judgments in face perception.

Eye can see right through you! Using eye movements to understand meta-cognitive processes when lying about confidence

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Criminal associates, such as terrorist group members, are likely to deny knowing other group members. The present research employed a 'concealed face recognition' paradigm to examine eye movements while participants lied and told the truth about different types of familiar faces. Participants were presented with colour photographs of male and female faces to which they made dichotomous 'familiar/unfamiliar' responses. Each response was accompanied by a confidence judgement (0-100%) for both honest and deceptive trials. Proportions of fixations in regions of interest were recorded using a head-mounted eye tracker at two decision points: 1) while the participant looked at the face when making the familiarity judgement, and 2) while the participant looked at the confidence scale when making the confidence judgement. Deceptive and truthful responses when denying knowledge of a face were associated with different patterns of looking behaviour. The pattern of eye movements when making confidence judgements also differed by veracity instruction. The potential for using eye movement behaviour as a means to identify manipulated confidence will be discussed.

The own-race bias is revealed by eye movements across converging memory procedures

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The own-race bias (ORB) is a well-documented effect wherein people from a majority race are better able to recognize own-race faces (OR), relative to cross-race faces (CR). Across three experiments, participants viewed Caucasian and Asian (OR and CR) faces while their eye movements and pupil diameters were continuously monitored. We indexed degrees of memorial specificity through converging behavioral paradigms, including remember/know, process dissociation, and directed forgetting. Oculomotor and psychophysiological measures observed during both learning and recognition estimated memorial strategies and cognitive effort. Across tasks, participants were better able to remember (but not "forget") OR faces, relative to CR faces. These behavioral findings were complemented by the psychophysiological estimates of memory: Eye movements and pupil dilation revealed that greater effort was devoted to encoding and recognizing CR faces, and that subsequent recognition was associated with more frequently reinstated eye movement patterns. Further, subjective strength of memory was revealed by eye movements and pupil diameters. Implications for theories of the ORB - in particular the race-feature hypothesis (Levin, 2000) - will be considered.

Scenes: Saliency, Objects & Memory

Gaze allocation to corresponding feature contrasts improves scene recognition performance

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Human observers recognizing familiar scenes from novel points of view have the problem that learned visual information is only partly repeated. Here, we investigated whether this characteristic of recognition under view changes fosters fixations on features that repeat from learning to recognition. In our eye tracking experiments, participants first learned real-world scenes from photographs and subsequently had to recognize different views of familiar among unfamiliar scenes. For the corresponding learning and recognition trials, we assessed individual attention maps via Gaussian filtering of fixation data. For each photograph, we computed feature contrast maps of color, intensity, and orientation by using the Saliency Toolbox [Walther & Koch, 2006, Neural Networks, 19(9), 1395-1407]. Finally, we calculated the correlations between individual attention maps and feature contrast maps. Scene recognition was more accurate when the fixated feature contrasts during recognition were similar to those during learning of a scene. When the task was to recognize a scene (but not during free viewing of repeated scenes), we also counted significantly more fixations in repeated than new image areas. Results point to different roles of repeatedly vs. newly inspected stimulus features for recognition.

Top-down but not bottom-up visual attention is mediated by parietal cortical areas during natural viewing

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Eye movements, a dominant human behavior, are influenced by bottom-up and top-down processes. Here we probe contribution and interaction of these mechanisms under natural conditions. We recorded electroencephalographic signals and eye movements while subjects were freely viewing grey-scale natural scenes. Images were presented in three conditions: unmodified, with increased (100%) or attenuated (-60%) peak luminance contrast at selected locations. Furthermore, we defined locations that were fixated more often than chance as empirical salient regions. Event-related potentials were computed time-locked to saccade onset. We found that (1) fixation probability at regions with enhanced or attenuated luminance contrast was strongly increased (65% and 48.5% respectively). (2) Surprisingly, presaccadic event-related potentials of saccades towards modified and unmodified regions were identical. (3) However, there was a significant difference between presumably top-down guided saccades towards empirical salient and control regions from -360ms on. The scalp topography of the presaccadic activation revealed polar effects between right prefrontal and occipital areas, suggesting a generating dipole at parietal regions. Our results indicate that bottom-up and top-down signals contribute separately to the guidance of eye-movements. The latter process is located in parietal regions and observable by scalp recordings; the former is presumably carried out by sub-cortical mechanisms.

Local rule violations attract attention and eye fixations

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We assessed whether local rule violations in images attract the eyes and attention (N = 38). We used patterns consisting of tiles, either forming a full regular pattern, or a locally irregular pattern. Within a visual search task, in half of the trials one of the tiles was rotated so as to violate the overall rule (here: point symmetry at all locations). Although this tile was anti-predictive for the target location (i.e. never at the target position), we found that participants significantly more often fixated on this image position than on every other location, and the mere presence of the rule violation (i.e. the rotated tile) slowed down correct target detection. Across three experiments, we also varied the local feature salience of each tile relative to its surround, and found this was without effect on attraction of the eyes and attention by the rule violation. Our results point to rule violations as one major origin of attentional attraction.

Ambient and focal processing in free viewing of meaningful images: A combined MEG and eye-tracking study

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When exploring new visual information, a substantial change in the viewing behaviour has been repeatedly shown. Early in scene exploration, fixations typically have short durations and increase over time, while saccadic amplitudes are larger at the beginning and decrease later on. The combination of short fixations and large saccades has been interpreted as an expression of ambient processing which is in service of global scanning and spatial orientation. The subsequent longer fixations in the context of shorter saccades have been related to focal inspection dedicated to the identification of certain object features [Pannasch et al., 2008, *Journal of Eye Movement Research* 2(2), 4:1-19]. So far the interpretation of these results is based on eye movement characteristics only. To contribute to this discussion, we recorded eye movements and MEG during free visual exploration. Earlier findings regarding the eye movement characteristics could be replicated. The MEG data support the hypothesis that brain activity differs for ambient versus focal gaze pattern. These findings provide converging evidence from behavioural and neurophysiological data for a shifting balance of at least two modes of visual processing during a free viewing of meaningful visual images.

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Visual distractor processing is sensitive to instruction: From eye-movement effects to fMRI analyses

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So far, there has been only mixed evidence from image inspection that the parameter of fixation durations is influenced by instruction. In the present experiment, two types of instructions were given to the subjects: They either had to inspect images to answer questions related to spatial layout or work in a more focused mode followed by an object recognition task. Additionally, in half the trials gaze contingent irrelevant visual distractors were presented during every 8th fixation. Without distractor presentation, longer fixation durations are obtained for the object recognition as compared to the spatial layout task. In an amplified form, the same result is reflected in the distractor related fixation prolongation. Distractors have a substantially higher impact on fixations in the object recognition than in the spatial layout task. Additionally, preliminary results of experiments replicating the paradigm with concurrent fMRI and eye movement recording will be presented. The results are discussed against the background of findings on distractor effect modulations due to saccadic context [Graupner et al., in press, *International Journal of Psychophysiology*]. Overall, the distractor effect paradigm emerges as a promising candidate for probing the nature of intrafixational information processing in the perception of complex images and scenes.

Representational similarity analysis of eye movements and brain-activity patterns

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Comparing neuronal activation elicited by complex eye movements may cause two major problems. The first problem is that eye movements in a magnetic resonance scanner may inflict strong stimulation in visual areas due to saccadic shifts. The second problem is that complex eye movement patterns are hardly to transpose in a sensible model for the common univariate approach. The representational similarity analysis helps to bypass these problems [Kriegeskorte et al., 2008, *Front Syst Neurosci*, 2(4),1-28]. In our study we measured eye movements for natural pictures of six different categories during free observation with a video-eyetracker. In a separate session BOLD-signals of the same subjects were induced by very short presentations of the identical pictorial set. By analysing the dissimilarity matrices of both the eye positional data as well as the brain activation patterns we revealed differences in the representation of visual categories in both modalities. The correlation of the dissimilarity matrices of both modalities revealed a close link between eye movements and BOLD in the fusiform gyrus. The BOLD signal pattern in these clusters may reflect the preparation of a set of saccadic eye movements which correspond to the eye movement in the free observation session.

Is guidance of search through scenes based on expectation of likely target locations, scene layout or both?

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Through repeated exposure to environments, we build long-term knowledge that affects expectations of where objects are likely to be situated. Research on scene gist suggests that this knowledge and actual scene layout are activated rapidly, influencing how we search for target objects. The present study explored the effect of expectation and actual target location on visual search by putting them in conflict. Objects appeared in an expected location, an unexpected but possible location (position violation), or not resting on a surface (support violation). In half the trials, a 250ms preview of the scene appeared before the target name to allow gist processing before search started. For objects in expected locations, there were faster responses, fewer fixations, longer fixation durations, and a longer time between first fixation and response. A preview benefitted only the support violation condition. Expectation drove search from the start; support violations influenced search only if introduced before the target name activated knowledge.

From eye movements during encoding to recall: Age effects in object location memory

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Object location memory involves processing object identities, spatial locations and binding object identities to locations. We investigated age effects in the relationship between eye movements during encoding and these aspects of memory. To do this, we recorded eye movements of younger and older adults while they viewed a photograph depicting 12 objects in a scene. After encoding, participants completed an object recognition task and either an object-to-location task or a location memory task. Younger and older adults had similar patterns of eye movements during encoding. Younger adults recalled more objects and placed more objects in their home locations compared to older adults. However, there were no age-related differences in memory for the spatial layout of the scene. Overall, fixated objects were more likely to be recognised and placed in their home locations compared to non-fixated objects. However, whereas multiple fixations on objects led to increased object identity recognition, object-location accuracy did not improve. Thus, we obtained a dissociation between encoding behaviour and memory for object identities, and between encoding behaviour and memory for object locations. We consider the results in relation to the Visual Memory Model [Hollingworth & Henderson, 2002, *Journal of Experimental Psychology: Human Perception and Performance*, 28, 113-136].

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On the visual span during object search in real-world scenes

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How much information do viewers obtain from fixations when searching for an object in a real-world scene? This question was addressed in two studies, using the moving window paradigm. Scenes were presented at a viewing distance of 90 cm, each scene occupying a 18.6 x 24.8 deg field of view. Exp. 1 featured window radii measuring 1, 3, 4, 4.7, 5.4, and 6.1 deg. Exp. 2 featured six window radii measuring between 5 and 10 deg. Outside the window, the image was low-pass filtered to impede the parsing of the scene into constituent objects. Visual span was defined as the window size at which object search times became indistinguishable from search times in the no-window control condition; this occurred with windows measuring 7 deg and larger. For windows smaller than 6 deg, search initiation times and fixation durations increased as the window became smaller. Scanning times roughly mirrored the pattern of reaction times. Verification time was inflated for the 1 deg window (only). In all window conditions, viewers adapted smaller average saccade amplitudes than in the control condition. Finally, there were noteworthy individual differences in span size and eye-movement behaviors.

The distractor effect in scene perception: Why some task aspects are of importance and others are not

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Presenting a mask during picture perception prolongs visual fixation durations during the scene offset as well as re-onset [Pannasch et al., 2011, *Attention Perception & Psychophysics*, 73(4), 1120-1132]. We investigated the strength of this distractor effect while subjects had to complete either a recognition or a change-detection task. In each task, the instruction was to focus either on the spatial layout of the scene or on the identity of the shown objects. The distractor effect was similar in both tasks but differed regarding the instruction: When focusing on the object identity a stronger prolongation was found but only for the scene offset. Thus, a modulation of the fixation prolongation occurs only if the visual input before the interruption is of relevance for the task, i.e. at scene offset. Furthermore, the results provide additional support for two distinct mechanisms of visual information processing (spatial layout vs. identity) in relation to differences in gaze behavior [Velichkovsky et al., 2002, *Transportation Research*, 5(2), 145-156]. These features of the distractor effect make its analysis a potential tool for accessing differences in information processes within single visual fixations during scene perception.

Spontaneous eye movements during visual mental imagery

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Aim: The present study examined the oculomotor behaviour during retrieval of information from long term memory while performing or not "visual mental imagery". **Methods:** Ten healthy subjects were asked to name French towns whose names began with a given letter (Semantic Task) then, they were asked to name towns that they could localize on an imagined map of France (Spatial Task). For each subject we compared the gaze location, at the time of pronouncing each town, with the real towns' locations according to the Global Positioning System (GPS) using bi-dimensional regression analysis. Specific tools developed by geographers were then applied to compare the map of France to its mental representation, reflected by the gaze positions. **Results:** Only in the Spatial Task, the gaze positions consistently correlated with the towns' GPS locations in all the subjects. Moreover, we could identify, for each subject, small chronological series of towns whose representation had specific deformation characteristics. **Conclusion:** Our results support that eye movements during imagery, reflect the spatial structure of the imagined scene and might play a functional role in generating and/or exploring mental images. Gaze positions can thus be used to study the dynamics of mental representations in healthy and pathological populations

Does imagination outperform visual cueing? Mental imagery vs. template search in (un)expected places

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Wolfe et al. [2004, *Vision Research*, 12, 1411-1426] and Bravo and Farid [2009, *Journal of Vision*, 9(1):34, 1-9] have shown that visual search is significantly faster when targets are cued visually ("templates") rather than verbally. This may be attributed to a more efficient generation of mental representations via templates and affects eye movements [Eckstein, 2007, *Journal of Neuroscience*, 27(6), 1266-1270]. Common target presentation times of around 200ms [Malcolm & Henderson, 2009, *Journal of Vision*, 9(11):8, 1-13], however, may simply be too short to generate mental representations from verbal cues. In the present study, we increased target presentation times to 5s. Significant differences between template and verbal cueing no longer exist: search times, saccade amplitudes, fixation numbers and distributions of fixation locations do not vary. This is true for expected and unexpected target locations. Expectations, however, affect search time (prolonged for unexpected locations) and eye movements (expected locations fixated first). We conclude that mental images cannot be generated instantaneously from verbal cues, but that mental imagery takes time. Mental images generated from verbal cues serve equally well as templates in visual search as do visual cues - and do not affect visual search strategies. Search is guided by top-down information.

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Scenes: Clinical

Restricted attention to faces in social scenes in schizophrenia patients

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Recent studies on gaze behaviour (GB) in healthy subjects suggested a preference for faces while scanning social interactions. This may be important for the well-known difficulties of schizophrenia patients (SZ) in the assessment of social interactions, as this group also shows deviant GB while scanning faces. To further elucidate this, we compared GB of schizophrenia patients (SZ, n=20) and healthy subjects (HC, n=39) during presentation of social interaction stimuli. Standardised pictures of social scenes were presented. Number of glances (GN), total and relative fixation duration (FD) and frequency (FN) in areas of interest ["face" (AOI-face) and "body" (AOI-body) region] were analysed. Significant differences were found for total and relative FN, FD and GN in the AOI-face. No differences were found concerning the relativised parameters in the AOI-body. Furthermore, significant correlations were observed regarding GN-AOI-face and the Global Assessment of Functioning (GAF) score. SZ didn't focus on the socially relevant facial information in the presented scenes as much as HC. This suggests that not only scanning of the informative face regions but also attention to faces in general is deviant in these patients. The correlation of GN-AOI-face and GAF-scores suggests that this difference has an important impact on social and vocational functioning.

Visual exploration and action processing in schizophrenia

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Visual scanning is widely reported to be abnormal in schizophrenia. The majority of studies monitoring eye movements in schizophrenic patients have used pictures of a face in isolation in free viewings. This study was designed to examine whether attentional control, through instructions, modulates the visuomotor behaviour in schizophrenia with pictures presenting a face accompanied by its body, and to investigate the ability of schizophrenic patients to recognize others' actions. Visual scan paths were monitored in twenty-six schizophrenic patients and twenty-six controls. Participants performed three tasks in which they were asked either to look at the picture in any way they liked ("free viewing"), to determine the character's gender, or to recognize the action the character was making with an object. Patients explored less the pictures than controls in the free viewing condition. Their scan paths did not differ from that of controls in the active viewing conditions though patients tended to "avoid" looking at the character's face in the action recognition task. The results are consistent with the literature on reduced exploration in schizophrenia in free viewing. They show that schizophrenic patients are able to normalize their pattern of exploration as a function of task demands.

Cognitive perspective taking during scene perception in Autism Spectrum Disorder and Typically Developed adults

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A recent study by Kaakinen, Hyönä, and Viljanen [2011, *Quarterly Journal of Experimental Psychology*, 1, 1-16] found that typically developed (TD) individuals modulated their eye movements according to perspective taking instructions during scene viewing. As an abundance of literature has indicated an impaired theory of mind in Autism Spectrum Disorder (ASD), we are interested to examine whether or not individuals with ASD would show this "perspective effect". In the current study, TD and ASD participants inspected pictures of a house under two simple processing instructions and pictures of another house under two complex perspective taking instructions. We anticipate that both groups will look at the target region in the simple condition more often and for longer durations when explicitly cued to look at those parts of the scenes, but we will find a weakened modulation of eye movements for the perspective taking task in the ASD group compared to the TD group. Our results will be discussed in relation to the complex information processing model of ASD [Minshew & Goldstein, 1998, *Mental Retardation and Developmental Disabilities Research Reviews*, 4, 129-136].

Viewing patterns and social-emotional insight in dynamic social scenes in children with Autism Spectrum Disorder (ASD)

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It is generally accepted that children with ASD show abnormalities in the processing of complex emotions in a social context and also exhibit atypical viewing patterns. We examined processing-viewing relationships in an eye-movement study with a social-emotional insight task. Two groups of 10-to-14-year old high-functioning boys, matched for age and IQ, participated in this experiment: an ASD group of children with a diagnosis based upon a multidisciplinary assessment according to DSM-IV-TR PDD-criteria and a typically developing group. Five dynamic episodes, selected from a Dutch-spoken soap series, were shown, while eye-movements were sampled monocularly at 500 Hz using an EyeLink II system. After each episode, a questionnaire was used to test the children's understanding of the social-emotional events. To analyze the eye movements, four dynamic regions of interest (ROI) were defined: face, body, objects and background. We first tested to what extent children with ASD showed atypical viewing patterns, with respect to global scanning parameters (e.g., fixation duration, saccadic amplitude) and relative to the ROI (e.g., focusing more on the background, focusing less on faces, alternating less appropriately between socially interacting individuals). Secondly, population differences in scan path parameters were related to differences in social-emotional understanding of events in the soaps.

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Eye fixation distribution in dysphoria: Is there a mood-congruent visual search strategy?

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Dysphoria has recently been associated with biased attention for emotional information. However, the nature of this bias should be further investigated, especially in rich contexts, where several types of information are available. In the present study, the 'naturalistic visual scanning approach' [Eizenman et al., 2003, *Psychiatry Research*, 118(2), 117-128] was employed to examine initial orientation of attention and subsequent eye fixation distribution in dysphoric and non-dysphoric individuals. Participants were eye-tracked as they viewed 4-picture slides convoking simultaneously 4 emotional categories: happy, sad, threatening, and neutral. Each slide was presented for 20 s., thus allowing a prolonged processing of emotional information. It turned out that dysphoric participants exhibited lower percentages of fixation number and fixation duration on happy pictures than their non-dysphoric counterparts. Interestingly, the percentages of fixation number and fixation duration were higher on happy pictures than on sad pictures in the non-dysphoric group, whereas no difference was found in the dysphoric group. Finally, mean glance duration and first fixation location were not affected by dysphoric status. This study confirms that dysphoria decreases focusing on positive material, but does not increase focusing on sad content. This is consistent with the assumption of an impaired mood-protective visual search strategy in dysphoria.

Eye movement behaviour in visual search tasks in mild alzheimer's disease

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Objectives and Study: In mild Alzheimer's disease (AD) patients experience an impairment of visual attention, traditionally assessed by paper-and-pencil tests. Eye movement behavior is related to performance in daily activities and consequently, to functional autonomy. The aim of this study is to evaluate visual exploration in patients with AD while resolving a set of visual search tasks using eye tracking techniques. **Methods:** 20 mild-to-moderate AD patients and 20 healthy elderly age-matched controls have been recruited through a memory clinic. Subjects are required to participate in a two-hour session in which neuropsychological assessment and a set of computerized visual search tasks are performed. An infrared eye-tracker is used to record eye movements. Evaluation criteria includes: task accuracy, reaction time, scanpath patterns and functional evaluation. **Results:** The study is currently in progress. Preliminary results show a divergence between groups in visual tasks performance. AD patients have longer reaction times and detect fewer targets than controls. Concerning scanpath patterns AD patients present shorter saccade amplitudes and longer fixation duration than controls. **Conclusions:** Preliminary results confirm previous findings about decline in spatial attention and visual exploration in AD. This study shows the contribution of using eye tracking technology for clinical AD assessment.

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Patterns of eye movements during cancellation tasks in stroke patients exhibiting hemispatial neglect

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To investigate whether hemispatial neglect occurs due to an information sampling deficit or impaired processing of information on the left we measured eye movements of stroke patients whilst they completed a sub-set of the Behavioural Inattention Test (BIT; Wilson et al., 1987, *Behavioural Inattention Test*. Suffolk, UK: Thames Valley Test Company) over three sessions. Participants who initially demonstrated left neglect in star and letter cancellation tasks exhibited a marked sampling deficit, with fewer visits being made and less total time spent on the far left regions of the stimuli. In the later testing sessions, a different pattern of eye movements emerged. The amount of time spent on the left increased and average gaze durations were inflated on the far left region compared with the other regions. However, behavioural measures (from the letter cancellation task) showed that, despite sampling of information on the left of the stimulus in the later testing sessions, neglect was still present, indicating a processing deficit. This suggests that, even though over time information on the left side could be fixated, the acquisition and processing of that information was impaired. Overall, these results demonstrate neglect can arise due to both information sampling and information processing deficits.

Face Perception

Gaze movements during expression identification on different face orientation

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The structure of face organization is the main determinant of the adequate identification of the facial expressions. Changing the face orientation leads to difficulties in face perception. We suggest that this difficulty can be described in the terms of gaze movements' specificity. We record eye movements during a face identification task in 6 conditions: normally oriented faces; faces rotated 180°; faces rotated 90°; faces rotated 270°, normally oriented faces with mouth and eyes rotated 180°; faces rotated 180° with mouth and eyes rotated 180° (as in «Thatcher illusion»). Gaze movements for normally oriented faces may be described as equal fixation duration for different face regions; greater dwell time for top part of the face and greater pupil dilation for the bottom part of the face. Different presentation conditions leads to partial destruction of such gaze movement structure. We suppose that this gaze structure changes are connected with changes in subjective importance of the expressive appearances, related to different facial features. It results in the changes of the subject's answers structure during the expression identification task.

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Tracking qualitative and quantitative information use during face recognition with a Dynamic Spotlight

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Facial information required to accurately individuate conspecifics is invariant across human beings, but the strategies used to extract this information are modulated by culture [Caldara et al., 2010, PLoS ONE, 5(3)]. However, it is still unclear how much information is necessary to effectively code information from the diagnostic facial features. To address this issue, we used during face recognition a novel technique that parametrically and dynamically restricts information outside central vision. We used Gaussian apertures centered on observers' fixations that dynamically and progressively expanded as a function of fixation time, at a rate of 1° every 25ms, such as the longer the fixation duration, the larger the gaze-contingent window aperture size. The aperture was contracted to 2° (fovea) at each novel fixation. To facilitate the programming of saccades and natural fixation sequences, we replaced information outside central vision with an average face template. The Dynamic Spotlight technique allowed us to finely estimate the information actively sampled during each fixation. Western-Caucasian and East-Asian observers use similar information for face recognition, but sampled from different favorite fixation locations, leading to specific visual inputs in terms of spatial frequencies.

Is the perceptual bias in face processing linked to an oculomotor bias?

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Previous researches demonstrated a left perceptual bias (PB) while looking at faces, observers using mainly information from the right half-face presented in their left visual field. Such bias is consistent with right hemisphere dominance for face processing and has been sometimes associated with more and longer fixations on right half-face for central or top and bottom presentations [Butler and Harvey, *Brain Res.*, 2006; Butler et al., *Neuropsychol.*, 2005; Hsiao and Cottrell, *Psychol Sci.*, 2008]. We further investigated this relation between the PB and the scanning of faces in two experiments during a judgment task. Normal and chimeric faces were presented parafoveally at the top, bottom, left or right of a central cross. Subjects remained fixated on the cross or executed up to three saccades on faces. Preliminary results showed that a left PB appears for chimeric faces when saccades were allowed (no PB observed for fixation). The oculomotor bias (OB) depends upon the position of face presentation (i.e. for faces presented left or right, the first saccade was oriented toward the closest half-face). Most important, no apparent link between OB and PB was noticed: the OB bias did not change depending on the PB, which did not fit the OB.

Gaze-contingency shows holistic face perception impairment in acquired prosopagnosia: Generalization to several cases

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By gaze-contingently revealing/masking a selective portion of the visual field, we showed that the face recognition problems of a brain damaged patient with acquired prosopagnosia (patient PS) are caused by a deficit in holistic face processing. Contrary to normal observers, PS's performance almost did not decrease by seeing only one feature at a time (foveal window condition), while she was largely impaired by masking the fixated feature only (mask condition), forcing holistic perception [Van Belle et al., 2010, *Journal of Vision*, 2009, 10, 1-13; *Neuropsychologia*, 48, 2609-20]. We extended these observations to two cases of acquired prosopagnosia with unilateral right hemisphere damage causing face-specific recognition impairment: GG [Busigny et al., 2010, *Neuropsychologia*, 48, 4057-92] and LR [Bukach et al., 2006, *Journal of Cognitive Neuroscience*, 18,48-63]. They completed a delayed face matching task in full view or with a gaze contingent window or mask. Similar to PS and contrary to normal observers, both patients were significantly more impaired with a mask than with a window, demonstrating holistic face perception problems. These observations support a generalized account of acquired prosopagnosia as a selective impairment of holistic face perception, implying that holistic perception is a key element of normal human face recognition.

Holistic vs. analytic face processing in congenital prosopagnosia

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Human faces provide important visual information for social communication and interaction. It is generally assumed that human faces are processed holistically and not only analytically. Local facial features are not perceived and represented independently of each other; instead, a face is perceived as an integrated whole. Prosopagnosia is a condition in which a person is not (or no longer) able to recognize faces of people known to the patient on the basis of visual perception. Using a paradigm with an eye contingent window and mask procedure, it has been shown [Van Belle et al., 2010, *Neuropsychologia*, 48, 2620-2629] provided evidence that acquired prosopagnosia is probably due to a failure of holistic face processing. Reports have also been described of people having difficulties recognizing faces from birth on, without demonstrable brain damage and who frequently have ancestors with the same problem. This is known as congenital or developmental prosopagnosia. In the present study, we examine analytic vs. holistic face processing in persons with congenital prosopagnosia.

The development of face specific looking pattern in infants

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Faces are special for humans, and even neonates prefer face-like images over images of other objects [Fantz, 1961, *Scientific American*, 204, 66-72]. However, the development of face perception is not fully understood. One approach to examining this issue has involved measuring infants' scan paths while they watched faces and comparing infant and adult patterns, since scan paths are influenced by the observer's cognitive process [Yarbus, 1967, In Yarbus (Ed.), pp. 171-211]. Thus, we presented infants aged 6-13 months with upright and inverted face-like images for 30 s each and compared the distributions of scan paths among facial areas. The results showed that young infants' scan paths were more diverse and repeated less frequently than those of adults. However, as they grew older, the diverse scan paths became concentrated on the features within the face (eyes, mouth, and nose), which is comparable to adult scan paths. Additionally, large individual differences in the sequences of scan paths decreased as a function of age. Given that this tendency was not observed in response to other types of images, our results suggest that a face-specific scanning pattern gradually develops at approximately 1 year of age.

Eyes like it, brain likes it: Tracking the neural tuning of cultural diversity in eye movements for faces

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Eye movement strategies deployed by humans to identify conspecifics are not universal. Westerners preferentially fixate the eyes and the mouth during face recognition, whereas strikingly Easterners focus more on the face central region. However, when, where and how Preferred Viewing Locations (PVLs) for high-level visual stimuli are coded in the human brain has never been directly investigated. Here, we simultaneously recorded eye-movements and electroencephalographic (EEG) signals of Westerners and Easterners during face identification of learnt identities. After defining 9 equidistant Viewing Positions (VPs) covering all facial internal features, we presented the learned faces centered on a random VP for 100ms. We then extracted from prior free-viewing fixation maps the average Z-scored fixation intensity for the non-overlapping facial VP regions (VPZs). Finally, we computed a component-free data-driven spatio-temporal regression between the VPZs and EEG amplitudes. This analysis revealed a universal direct relationship between VPZ and EEG amplitudes over the face-sensitive N170 network at around 350ms, an effect unrelated to a burst of microsaccades occurring in this time-window. Our data show that the distinct cultural fixation preferences for faces are related to a universal post-perceptual tuning in the occipito-temporal cortex. Culture shapes visual information sampling, but does not regulate neural information coding.

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Perception, Attention & Memory

The influence of an audio-visual spatial illusion on saccadic eye movements

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Based on the proposed functional roles of the dorsal and ventral visual streams, numerous studies have examined the dissociation between perceptual and action systems using a variety of techniques ranging from clinical neuropsychology to brain imaging. There is a strong debate regarding the extent to which the perception/action dissociation extends to illusions and whether these illusions influence saccadic eye movements. In this study we take advantage of a novel audio-visual illusion introduced by Hidaka et al. [2009, PLoS ONE 4(12)] in which an alternating sound can induce a strong illusion of visual motion for a static bar flickering in the periphery (Sound Induced Visual Motion, SIVM). We tested whether the illusory position of the bar influenced saccadic landing positions. The flickering bar was presented either with the auditory stimulus (SIVM) or no auditory stimulus, and the task was either to report the horizontal motion (on fixation trials) or to make a saccade to the final position of the flickering bar. Our findings indicate a tight coupling between the perceptual and visuo-motor results with saccades amplitude being significantly influenced by the expected landing position of the illusory bar.

Perception and oculomotor actions: Further evidence of no dissociation with the Titchener Circles illusion

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A recent metanalysis of published Müller-Lyer illusion studies [Bruno et al, 2010, Vision Research, 50:2671] suggested that once a number of saccade-specific factors were taken into account, no dissociation between perception and oculomotor actions (saccades) was generally present. What of other illusions? We exposed five subjects to the Titchener circles illusion (targets placed on the horizontal meridian of a single circle, CON, are perceived as being closer than those placed with the same separation on two separate circles, EXP). After a randomised fixation time leftward or rightward CON or EXP stimuli (target separations 2°, 4° or 6°) or point target control stimuli (2°, 6°) were presented (one target at fixation) for 200ms. In the perceptual experiment subjects verbally reported the distance from the fixation target to the eccentric target relative to a standard line. In the saccade experiment, eye movements were recorded using infra-red oculography and saccade latency and amplitude measured offline. Intersubject mean (\pm SD) perceptual effect size (EXP-CON/Control) was $9\pm 6\%$, compared to a saccade effect size of $9\pm 4\%$. Thus, as with Müller-Lyer, there is no evidence with Titchener circles of a perception/(oculomotor) action dissociation.

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Illusory depth changes and their reflection in eye movements

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To clarify some issues concerning the influence of visual illusions on the oculomotor activity, we compared the eye movements recorded with the iView X system (SMI) in the cases of viewing natural and stereoscopic images at various depths, as well as in conditions of experiencing two different illusions producing significant changes in perceived depth. The following four series of experiments were performed in which the subject's tasks were: (1) to read a printed text presented at various distances; (2) to read similar text presented on 3D display (HYUNDAI) with circular light polarization, the perceived depth being varied by binocular parallax; (3) to observe a large Necker cube counting illusory jumps of its frontal side forward and backward; (4) to look at the top of a reversible illusory stereokinetic cone produced by rotating a disk with an eccentric ring pattern. In Experiments 1 and 2, the interposition of the left and right eyes correlated well with perceived depth that was true in the former and virtual in the latter case. In Experiments 3 and 4, there were no evident manifestations of the illusory depth changes in the records of eye movements.

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Evidence, not confidence, impacts on eye movement decision making

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We are constantly making decisions about which object should be selected as the target of the next saccade on the basis of incomplete information from the environment and our confidence in that evidence. Here we examine which of these (environment or confidence) has the greatest impact on saccade execution. Participants were required to make a saccade to one of two targets indicated by the motion within a Random-Dot Kinematogram and then to indicate their confidence. The amount of dots supporting the target choice was manipulated. Over a block of trials separate participant groups were given feedback indicating that 70% of their decisions were correct (High confidence) or incorrect (Low confidence) prior to completing a true feedback block. Significant differences were found in the confidence ratings between those participants in the high confidence condition and those in the low, and this difference persisted into the second block. However, there were no significant differences between the saccadic measures of the two groups of participants. Both groups showed a similar significant effect of motion coherence level on several eye movement metrics. This suggests that the external evidence is more influential than confidence on the competitive process that leads to the target choice.

Visual search strategies in the contrast sensitivity task in mesopic and photopic conditions

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Eye movements are recorded when accomplishing contrast sensitivity task in mesopic and photopic conditions. Subjects are seated in front of an experimental chamber illuminated by different light sources (sodium lamp, light-emitting diodes). Inside the chamber they view a sheet of paper with different contrast targets arranged in line with increasing contrast. The subject's task is to find as quickly as possible a target with just noticeable contrast then fixate the gaze on it and respond with button press. Visual search strategies are evaluated for different light sources at different luminance levels. Few processes in contrast detection strategy were revealed. Visual search usually starts from low contrast targets which are not recognized by peripheral vision. Then the subject's gaze moves towards higher contrast targets which are just recognized, but does not go towards high contrast targets, which are noticed with peripheral vision as not interesting. The gaze moves back and forth with diminishing amplitude in the previously defined region with longer fixation time for critical targets until the subject decides which contrast is just seen. At mesopic conditions the region of interest is bigger, the overall search time is longer and more fixation time is spent on critical targets.

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Surface but not contour influences saccade metrics in two-stimulus visual displays

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When a peripheral saccade-target object is simultaneously presented with a distractor, the eyes tend to move towards an intermediate location between the stimuli (i.e. the Global Effect). To investigate the role of contour extraction in the computation of saccade metrics, we tested whether the global effect can be modulated by the spatial arrangement of the pixels that compose a distractor. The distractor, always less eccentric than the target (a circle), consisted of 16 vertically- or horizontally-arranged pixels that were either aligned (solid line) or misaligned by 0.1 or 0.2°. Since contour neurons in V2 stop responding when non-collinear instead of collinear dot stimuli are presented in their receptive field, we expected that non-collinear distractors would less largely deviate the eyes from the target than collinear ones. Results showed to the contrary that distractors produced greater deviations as they became less collinear. This effect, observed for short- (80-171ms) as well as long-latency saccades (220-266ms), and for both vertically- and horizontally-arranged dot stimuli, most likely came from non-collinear distractors covering a larger surface, and hence recruiting a greater population of neurons within the Superior-Colliculus map. Thus, contour information did not build up rapidly enough to influence saccade metrics, unless its effects were overridden by the prominent role of surface.

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Finish search, stop inhibition: Inhibition of return across two searches

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Inhibition of return (IOR) is an important factor in visual search that discourages reinspection of recently inspected items. We have previously demonstrated that IOR acts within two consecutive searches in the same display but that it is not maintained across two searches. Here we investigated whether it is the completion of the first search that resets IOR. We had participants search the same display twice consecutively. On half of the trials, they were allowed to complete the first search whereas on the other half search was interrupted unexpectedly by the start of the second search. In both conditions, we probed either a recently inspected item of the first search (old probe) or a non-inspected item (new probe) immediately at the beginning of the second search. As expected, saccadic latencies to old and new probes did not differ when the first search was completed. However, when the first search was interrupted, latencies to old probes were longer compared to latencies to new probes suggesting that IOR was not reset in this case. These findings are further evidence for the flexibility of IOR: Resetting IOR after the end of a search ensures that a further search is not affected by inhibition processes.

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Blanking the display disrupts memory in repeated visual search

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When participants search the same letter display in two consecutive searches for different targets, they find the second target faster when they had fixated it recently in the first search. This recency effect also occurs when a short delay is introduced between searches. Even if the letters switch positions after the first search participants preferably search for the second target at its original position. Here we were interested in whether the continuous presence of the display during the delay is necessary to sustain memory across searches. We introduced a short delay between searches during which either placeholders were presented or the display was blanked completely. After the delay the letters either interchanged their positions, retaining the spatial layout of the display (switch display), or the original display returned (static display). With placeholders the recency effect was still present in static displays. Even in switch displays subjects moved their eyes to recently inspected locations although they knew that the target was no longer there. When we blanked the display these effects were somewhat diminished. We conclude that blanking the display (rather than replacing it with placeholders) is better suited to disrupt the memory responsible for the recency effect.

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Using visual interruptions to explore the extent and time course of fixation planning in visual search

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In a single experiment, we examined fixation planning in visual search. Participants searched for a simple target in a display (a T-shape amongst L-shapes), and, on most trials, the search display was removed from view and replaced with a blank-screen (a visual interruption trial). After a pre-determined period of time had elapsed (1200-1400ms), the blank screen was replaced with the original search display. We also varied the duration that the search display was visible prior to an interruption (100-1100ms), to examine the time course of fixation planning in search. The data revealed that participants continued to fixate locations that had contained objects during the interruption, i.e. when no objects were present, suggesting that search continued even when the display was no longer visible. Furthermore, when the display reappeared, revisits were not made to all of the objects that were fixated during the interruption. Finally, variance in the pre-interruption duration had a minimal impact on the findings. Together, the data suggest that fixation planning develops very rapidly following the presentation of a search display, and continues to be executed even when no display is visible. We discuss findings in relation to planning and memory processes involved in visual search.

Using magic to reconcile inattentive blindness and attentional misdirection

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Recently, Memmert [2010, *Consciousness & Cognition*, 19, 1097-1101] argued for an empirical dissociation between inattentive blindness (IB) and attentional misdirection (AM) paradigms, citing four important differences between protocols within each field of study. Following the lead of Kuhn and Tatler [2005, *Perception*, 34, 1153-1161], we have developed a magic trick for use in eye-tracking experimentation that has properties which make it ideal for reconciling the differences highlighted in Memmert's critique, while maintaining the ecological validity that many experiments in IB lack. In the magic trick, a coin placed beneath a napkin disappears, reappearing under a different napkin. Depending upon the condition, in some instances participants were also required to identify a briefly presented visual stimulus. Careful attention during the trial would allow a participant to detect the "secret" event that underlies the illusion, as the event happens in full view. The magic trick has been used to successfully replicate results across the IB and AM literatures, including the common finding that IB cannot be predicted by the locus of fixation, relative to the IB stimulus. We will show how the magic trick can be manipulated to address each of Memmert's points.

Linguistically and visually driven attention in multimodal change detection tasks

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Two eye-tracking studies investigated the coordination of linguistically and visually driven attention in multimodal change detection. We asked whether changing visual objects capture overt attention and interact with linguistically driven attention while people are performing a linguistic change detection task (Exp1) and whether linguistic focus and linguistic changes affect visual change detection performance (Exp2). In both experiments, participants heard three-sentence stories that were accompanied with complex visual scenes in a 2x2x2 design: (focused/unfocused, linguistic change/no_change, visual change/no_change). Linguistic and visual changes occurred in same target words. The concurrent visual change elicited shorter LogRTs in the focused but not in the unfocused condition in Exp1. Linguistic context elicited shorter LogRTs when the unfocused stories also contained a linguistic change than when the story stayed unchanged; but no difference in focused stories in Exp2. Eye movements showed longer target dwell times for changed objects compared to the unchanged objects in both experiments. Focus condition also elicited shorter total dwell times compared to the unfocused stories in the visual change detection task. The studies show that even though the tasks require reliance upon either linguistic or visual memory representation, complex interactions are found between linguistically and visually driven attention mechanisms.

Attentional bias to alcohol related stimuli in high and low craving social drinkers: A flicker change blindness study

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Several theories of addiction posit that drug related stimuli, through processes of classical conditioning, are able to elicit physiological and subjective craving [for review see Franken, 2003, *Progress in Neuro-Psychopharmacology & Biological Psychiatry*, 27, 563- 579]. Attentional bias to drug related stimuli is argued to be a key mechanism in this process, however, its role and mechanisms remain inconclusive, possibly due to methodological limitations and an over reliance on indirect measures of attention [for review see Bruce & Jones, 2006, In Weirs & Stacy (Eds), pp. 135-149]. The present study measured eye movements whilst participants completed a flicker change blindness task using both simple stimuli and real world scenes with both an alcohol and neutral change competing for detection. Results demonstrated that levels of craving were not indicative of levels of consumption in social drinkers. Furthermore, in real world scenes only, high cravers detected a greater proportion of alcohol related changes compared to low cravers and were also quicker to initially fixate on alcohol related stimuli. These findings will be discussed in terms of contemporary theories, individual differences in motivational salience, ecological validity of stimuli and the possible impact of search strategies in simple stimuli.

Orienting Response

The remote distractor effect and saccadic inhibition

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The appearance of a visual distractor, remote from the saccade target, results in an increase in mean latency termed the 'remote distractor effect' (or RDE). The RDE is greatest for distractors at the fovea, and decreases systematically as distractor eccentricity increases from fixation. In what may be a related phenomenon, termed saccadic inhibition (or SI), an irrelevant stimulus onset can suppress saccades occurring at around 80-100 ms after the transient onset. It has been suggested that the characteristic 'dip' observed in the underlying latency distribution, for short-latency saccades, may underlie the remote distractor effect [Buonocore & McIntosh, 2008, *Experimental Brain Research*, 191, 117-122; Reingold & Stampe, 2002, *Journal of Cognitive Neuroscience*, 14(3), 371-388]. Here we examined the systematic effect of manipulating distractor eccentricity on the RDE and also on the 'dip' in the early portion of the underlying latency distribution that is taken as the hallmark of saccadic inhibition.

Gaze-contingent changes influence the visual fixation duration: An interaction of relevance and modality

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Suddenly appearing events lead to a substantial prolongation of the affected visual fixation. This effect was shown to habituate with repeated distractor presentation, making an interpretation within the framework of the orienting reaction (OR) plausible. The relevance of a stimulus is another important aspect for the elicitation of the OR. Here, we investigated if distractors of different relevance characteristics can modulate the effect of fixation prolongation. During free image exploration, distractors were presented 100 ms after the onset of every 5th fixation. Within an image, distractors of two different modalities and forms (visual, upright and flat ovals; auditory, high and low pitch) were shown, all with about equal probability. One group of subjects was instructed to pay attention to one certain type of distractors (silently counting), while the other group had to ignore them all. A difference between the groups was found with stronger fixation prolongation in the counting condition but only for visual distractors. No differences were found within groups for distractors of the same modality. The modality dependent effects for relevance are in contrast to the interpretation in terms of the OR. The data rather suggest interference due to central processing limitations and its interaction with oculomotor behaviour.

Can saccade choice and latency be experimentally dissociated?

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At the heart of all modern - "the first-to-threshold" - models of saccadic decision is a fundamental relationship between choice and speed (see Bompas & Sumner, symposium "How does 'when' relate to 'where' in saccadic decisions"). This relationship should be most evident when choice is inconsequential, since there is no need for top-down factors to interfere with bottom-up competitive accumulation. We used magnetoencephalography (MEG) to design a critical test for this relationship. Participants made saccades to single target onsets (left or right), and on one third of the trials had to choose freely between two simultaneous targets (left and right), while eye movement behaviour was recorded using EOG. We then identified in the brain the sources of variability accounting for i) speed in single target trials and ii) choice in double target trials, at various stages of the decision process: from pre-stimulus baseline until the oculomotor response. Our results suggest that determinants of speed and choice are at least partly dissociated. We conclude that free choice is only partially accounted for by noise within a bottom-up competitive accumulation to threshold process and that it is illusory for models of saccadic decisions to ignore top-down factors.

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EEG investigation of saccade preparation in the "double step" experimental scheme

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We investigated ERP potentials that were related to the switching on of the first visual stimulus of two successive stimuli in the "double step" experimental scheme (pulse-overshoot) and the latency of visual-guided saccades depending on the length of the first stimulus. It was shown that the latency of evoked P100 and N150 potentials were increased if a saccade to the first stimulus was absent. This may reflect the influence of competitive inhibition of the first saccade's motor program in the process of interference of the visual stimuli. Parameters and topography of evoked and slow presaccade potentials reflect activation of main cortical zones of saccadic control and the top-down mechanism of fronto-media-thalamic system of selective attention. Our findings allow us to suppose that programming of two saccades or a single second saccade in the "double step" experimental scheme are determined by not only completeness of the stage of decision-making about first saccade initiation to the moment of second stimuli, but also the processes of covert attention in the period of stimulus expectation. We suppose that the patterns of saccade responses might be defined by direction of covert attention.

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A size-latency principle for saccadic visuomotor planning

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Saccade reaction times (SRTs) are strongly determined by the spatial scale of attention: SRTs are short for targets beyond the attended field, but, when targets step within the attended area, SRTs are proportionally longer for saccades that are small relative to the attention field size. Previously, we demonstrated this "size-latency effect" using a demanding discrimination task that engaged and fixed attention at a particular scale. Now, we test the broader generality of this effect by simply using rings of different diameters without an attention task. All ten subjects showed robust size-latency effects to steps of simple ring stimuli, with significantly longer SRTs to targets that stepped by less than the ring diameter. If the fixation target stayed on (overlap condition) or switched off 200ms before target onset (gap condition), similar size-latency curves resulted, but shifted by approximately ± 30 ms, respectively. Delayed saccades in which the GO signal was an auditory cue, rather than fixation offset, showed no size-latency effect. We conclude that there is a general and obligatory size-latency effect that requires a visual transient, forming a visuomotor planning principle based on the cost vs. benefit of making an immediate saccade.

Chinese "Express Saccade Makers": Analysis of antisaccade performance

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Express saccade makers (ESMs) produce high proportions of express saccades (ES; latency 80-130ms) in overlap trials (fixation target present when saccade target appears). We recently reported that ESMs were much more common than expected in the Chinese population (Amatya et al, 2011, EBR210:117). A group of 76 naive Chinese subjects (median age: 24y) were exposed to 2 x 200 overlap or antisaccade trials (targets 10° left/right randomised, randomised fixation time 1s-2s, order of blocks randomised between subjects). Eye movements were recorded using an infrared reflectance eye tracker. Overlap tasks revealed 17 of 76 subjects (22%) were ESMs (mean percentage of ES- ESM:40±7%; Non-ESMs:10±7%). Antisaccade directional error rate was slightly higher in ESMs (ESM:41±24%; Non-ESM:29±22%; NS). Error prosaccade latency was lower in ESMs (ESM:164±35ms vs Non-ESM:194±19ms) and antisaccade latency longer (ESM:290±37ms vs Non-ESM:282±47ms). When tested with ANOVA both latency (within subjects) and group (between subjects) were significant ($p < 0.001$). These results confirm that ESMs are more common among Chinese subjects and suggests that performance is related to generally low pro-saccade latencies across task types.

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Quickness of saccades and the daily amount of video games

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The effect of video games on human behaviour is often addressed by indirect measurements. To study effects on attention processing directly, we examined saccades of 25 non-players (daily gaming time < 1 hour/day) and 30 players (DGT \geq 1 hour/day). In two paradigms we analyzed the quickness and precision of saccades. First, our subjects performed a sequence of two saccades using inter-stimulus intervals (ISI) from 50 to 500 ms. In the 50 ms condition, the frequency of the first saccade was significantly reduced and by trend higher in players compared to non-players. Players also had significantly shorter latencies than non-players for all ISIs. Second, our subjects performed anti-saccades. We found no significant difference in the frequency of pro-saccades in players and non-players. Latencies of pro- and anti-saccades were again significantly shorter in players compared to non-players. In summary, players had shorter latencies than non-players in both paradigms. In the case of anti-saccades, the decrease in latency was not due to an increase in error rate. Therefore, we think that video games speed up attentional processing underlying saccades but leave the executive control function mediated by the frontal cortex unchanged.

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Tracking

A model with uncertainty unravels saccade-pursuit synergies

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The objective of this study is to model the interaction between different types of eye movements in the head unrestrained condition. We focus on the two main types of orienting eye movements: saccades and smooth pursuit. Indeed, in order to improve the perception of targets, the oculomotor system synergistically combines them. In contrast with previous models, retinal inputs are represented, here, as noisy signals. Therefore, position and velocity errors must be estimated through Kalman filtering. The goal of these filters is to better illustrate the way the brain works, with uncertainty evolving over time. These estimations are then processed by the pursuit and saccadic systems and converted into motor commands. In parallel, the decision to trigger (or not) a saccade is taken. This question can be viewed as a speed-accuracy trade-off: the more you wait before generating a saccade, the more accurate the saccade will be and vice-versa. Our model can also account for the predictive mechanisms observed in the absence of visual feedback (target blanking). This model is the first to have non-deterministic inputs to model the oculomotor system. Thus it is more realistic and explains in a more natural way the interactions between saccades and smooth pursuit.

Evolution of the visual tracking performance across childhood

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The study of eye movements in children is an important topic, informing us about the brain maturation. As a fine combination of smooth and saccadic eye movements is used to keep a clear vision when exploring our environment, we were interested in studying the interaction between these two kinds of eye movements in children. We recorded horizontal eye movements in 55 children aged 5 to 16 and in 15 adults. We used the double step-ramp paradigm that consisted of a first ramp at a constant velocity (15deg/s). After a random duration, the target could step either 10 deg to the left or 10 deg to the right (position step) and continued moving but with a different velocity. The change in velocity (velocity step) ranged from -45deg/s to 45deg/s. We demonstrate a remarkably good general oculomotor behavior in children (starting at 5 years) with evolving performance with age concerning the smooth pursuit, saccadic system and the interaction between both. We found increasing acceleration and gain of the smooth pursuit with increasing age and decreasing saccadic latencies with age. We also studied the way position and motion signals are taken into account and combined for an adequate visual tracking.

Eye tracking evidence for action simulation

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Action simulation is believed to be a core function of the human mirror system, allowing us to predict actions and possibly learn new actions. However, direct measures of ongoing action simulation are hard to obtain. The present study explores the role of eye movements as an implicit and online measure of action simulation. Participants viewed predictable sequences of natural, goal-directed actions which were occluded for a two second period. Following occlusion, the action sequence reappeared at three levels of temporal asynchrony. Participants were instructed to imagine the continuation of the action during the occlusion period and to make a judgement about the temporal coherence of the sequence. During natural viewing and occlusion, eye movements were recorded. Significant correlations between eye movements during natural viewing and during occlusion are reported. This suggests that eye movements continue to track an action during occlusion, indicating ongoing action simulation in this period. Moreover, results indicate that stronger eye movement correlations across participants predicted better behavioural performance. Further work should assess the functional role of these eye movements for accurate action prediction.

The role of prediction in dynamic motion integration for smooth pursuit

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The aperture problem causes a bias in the initial tracking response to a translating tilted bar in the direction orthogonal to the bar-edge. A dynamic solution to this problem and the corresponding reduction in the tracking bias could be mimicked by a recurrent Bayesian network [Bogadhi et al., 2011, *Vision Research*, 51(8), 867-880]. This framework could be extended to understand more generally the interaction between sensory and predictive signals. Here, we investigate the role of prediction in dynamic motion integration by manipulating the local motion signals. The stimulus is a bar translating at constant speed and whose orientation starting at either 45° or 90° changes as a sinusoid with one of the three frequencies (0.05Hz, 0.1Hz, 0.2Hz). Subjects (n=6) are instructed to track the center of the bar. No significant correlation of the vertical eye velocity component with the input sinusoid is observed. Nevertheless, when there is a 90°-change in orientation of the tilted bar either abruptly, during visible motion, or after a short blank (200ms and 400ms), the vertical component of tracking response is correlated with the change. This suggests that the system could predict and thus minimize the effects of the sinusoidal changes in the target orientation but not abrupt changes.

Eye movements in reading drifting text

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In two experiments we investigated the interplay of smooth pursuit and saccadic eye movements while participants read drifting text. The text moved either vertically (upwards or downwards and at 5.52 or 7.05 °/s) or horizontally (leftwards at 10.57 or 14.09 °/s). In all conditions we extracted eye position tracks from 50 ms before the onset of forward saccades to 100 ms following saccade onset. The horizontal amplitude of saccades in the horizontally drifting text condition was obtained by interpolating the smooth pursuit track in the phase directly preceding and following the saccade. The position tracks and the corresponding speed tracks were baseline-corrected by subtracting the tracks corresponding to saccades with a comparable horizontal amplitude obtained from a condition in which the participants read non-sliding text. We found that smooth pursuit was substantially identical in the 50 ms preceding saccade onset and from 50 ms to 100 ms post-saccade onset, with gain values between .94 and .977. Moreover, at least for the initial phase of the saccade, the smooth pursuit component adds to the fast component. In general, the present results indicate that the oculomotor system efficiently combines smooth pursuit and saccades to achieve word targeting on a dynamic display.

Curvilinear self-motion and gaze movements: Drivers cannot fixate the tangent point

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Many studies have shown that while cornering, drivers have gaze fixation patterns in the vicinity of the tangent point (TP). The TP interest is mainly due to (1) its angular position linked to the road curvature; and, (2) its minimal speed in the optical flow (OF). However, the TP is only motionless when the trajectory follows the curve's geometry. In the present study, we measured gaze behavior during simulated curve driving, with the general hypothesis that gaze cannot be stable when exposed to motion. Results show that gaze position is located near the TP. In addition, we observe a systematic optokinetic nystagmus (OKN) around the TP position. The OKN slow-phase direction does not match the foveal OF direction, while slow-phase speed is about half the local speed. When averaging the flow on larger areas, gaze and flow directions match better, and gaze and flow speeds are optimally matched for an optic flow integration over two degrees. We thus confirm that the TP is a privileged feature in the dynamic visual scene. However, studying only gaze fixation is not fully relevant, because the TP is surrounded by OF, whose global characteristics induce retinal drifts and lead to OKN behavior.

Neural control of saccades toward a moving target: Effects of inactivating the fastigial oculomotor region

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The “dual drive” hypothesis proposes that the generation of saccades toward a moving target involves two parallel streams. One stream would carry a drive based on initial target eccentricity while another stream would compute the complementary drive required to compensate for the target motion until the time when the saccade ends. These two commands would converge on the saccade generator. The first drive would originate from the deep Superior Colliculus and the compensatory drive from the Cerebellum, possibly the Fastigial Oculomotor Region (FOR). This hypothesis was tested in two monkeys by studying the consequences of inactivating the FOR on the accuracy of saccades toward a moving target. The task was to track a central visual target which moved toward the periphery with 4 different velocities. In addition to the dysmetria of saccades, the pursuit gain was increased for ipsilesional target motions and decreased for contralesional ones. Thus, gaze always lagged behind the target during contralesional target motions whereas it often led the target during ipsilesional ones. Irrespective of the direction of target motion, the amplitude of first catch-up saccades increased with target speed. In other words, target speed signals can reach the saccade generator even when the FOR is inactivated.

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Neural control of saccades toward a moving target: Effects of a spatiotemporal perturbation by deep Superior Colliculus microstimulation

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It has been established that the saccade system is able to compensate for changes in eye position induced by electrical microstimulation of the deep Superior Colliculus (dSC) in order to bring the eyes toward the location of a flashed target. This finding indicates that retinal signals are associated with eye movement-related signals for generating accurate saccades. In this study, we tested the extent to which the saccade system is able to compensate for unexpected changes in eye position (CEP) when orienting gaze toward a moving target. The following eye tracking task was used in two rhesus monkeys. After stepping relative to the straight ahead direction, a target continuously moved in the orthogonal direction with two different speeds (20 and 33°/s). After a duration of 150 ms, the target motion was blanked for 150-300 ms. In 50% trials, a CEP was induced by dSC microstimulation (27 tested sites, 30-45 ms, 400 Hz, 12-20 microA) when the target was blanked. The results reveal elastic mechanisms in the brain for orienting the gaze toward a moving target.

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Gaze & Action: Clinical

Evaluation of mental fatigue by eye and hand movement parameters

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A person performing a mentally demanding task for an extended period of time becomes increasingly fatigued which leads to decreased performance and higher probability of mistakes. Increased levels of mental fatigue and workload also influence the parameters of saccadic eye movement, fixations and eye-hand coordination. To evaluate changes in eye gaze parameters and eye-hand coordination we used an experimental design allowing us to induce moderate levels of mental fatigue and monitor subjects' performance. For one hour participants had to solve sums shown on screen as quickly as possible. Then possible answers appeared on mouse click and the subject had to find and click on the correct one among the presented options. This allowed for assessing patterns of attention shifts between the sum and the answers and strategies of correct answer search. Time of saccade onset in relation to answer appearance and the beginning of hand movement is analyzed. As mental fatigue developed parameters of fixations and saccades as well as eye-hand movement correlation changed. The further development of this approach will promote working out of a contactless mental fatigue detection system.

Alcohol effects on eye and hand movements during different attention processes

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Alcohol affects a variety of human behavior, including visual perception and motor control. This study was designed to compare alcohol effects on WHEN and WHERE processes of visual attention changed. Eye and hand movements were recorded during the tracking of the main target moving in a circular path. The second moving target appeared sometimes in the central region of the field. The subjects track the movement of the target by using a mouse - driven cursor and responded to the appearance of the second target in two ways. In experiment 1, the eye and hand motor systems produced well-aimed movements on the second target and the subject pointed to it by clicking on the mouse button (dual-task condition, WHERE process). In experiment 2 instead of a goal-directed hand movement to the target stimulus, subjects had to make only a click of the mouse button on the main target (WHEN process). Healthy adults performed both tasks under 0.1 g/kg doses of alcohol. The results showed that RT of the click of the mouse button of the second target were on average twice longer in the dual-task condition than in the single-task condition, and after alcohol dose this difference increased even more.

Quantitative assessment of driving performance in Parkinson's disease (PD): Deficient coordination of gaze-hand-feet-control

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During driving, smooth pursuit eye movements (EM) appear as dynamic fixations on to moving targets, preventing saccadic degradation in case of a lost target. Parkinson (PD) patients show inaccurate static and dynamic fixations during driving with consecutive loss of targets and deficient driving performance.- We recorded and analyzed driving performance of 20 PD patients and 20 age matched healthy subjects using an (EM) infrared system within a driving simulator, recording also steering, indicator & accelerator/ brake signals. All patients were on dopaminergic medication and were treated with an implanted STN(sub-thalamic nucleus) stimulator that was either ON or OFF while driving.- Compared to approximately normal driving (Average errors (AE): 10.4), PD Patients with STN On (AE: 20.9) drove worse; PD Patients with STN Off, medication ON demonstrated a lot more traffic errors (AE: 24,6); PD Patients in a total Off-condition showed the highest number of traffic errors (AE: 27,1). Comparing the driving time, with STN stimulator ON they needed on average(AV) 258sec, i.e. the upper limit of the normal value (AV 231). PD Patients in total Off-condition needed AV 278 sec. Gaze and steering movements were closely correlated. Our recordings demonstrate the acute improvement during a complex attention-coordination task through the STN ON condition.

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Reflexive saccades are abnormal in Parkinson's disease

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Volitional saccades in Parkinson's disease (PD) reveal clear deficits, with increased latency and decreased amplitude evident even on clinical examination. This is in contrast to reflexive saccades to exogenous stimuli, which have typically been regarded as normal. With a large and well-characterised sample, we aimed to determine whether they are normal, or are actually impaired but to a lesser extent than in volitional tasks. We compared 47 healthy elderly controls to 138 people with Parkinson's, 84 of normal cognition (PDN), 34 with mild cognitive impairment (PD-MCI), and 20 with PD dementia (PDD). They performed 108 randomised reflexive saccade trials with either no temporal gap (step task), a 200 ms gap, or 200 ms overlap between successive stimuli (a red target jumping from 5-20 deg). Multilevel regression models showed that all three PD groups had decreased primary saccade gain. PDN had normal latencies in the three tasks while PD-MCI and PDD were progressively prolonged. In the PD groups, latency and gain correlated with measures of motor disease severity (UPDRS-III) and global cognitive status (Montreal Cognitive Status). Previous conflicting findings may have been due to heterogeneity of disease severity across samples. Cognitive status in particular must be accounted for.

Sensitivity to irrelevant distractors in a memory guided sequence saccade task in patients with mild Parkinson's disease

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Patients with Parkinson's disease (PD) demonstrate impaired performance in memory guided sequence saccade tasks, where patients are asked to saccade to the remembered locations of a sequence of targets. Patients, unlike healthy participants, typically make a series of small (multi-step) saccades to the remembered position of the target and produce an abnormally inaccurate final eye position (FEP). Such impairments may reflect both a motor and visuo-spatial working memory (VSWM) component. This study examined the sensitivity of VSWM to irrelevant distractors in patients with mild PD. The presence of an irrelevant distractor stimulus at fixation was interpolated with the presentation of each of four to-be-remembered targets. Patients with mild PD exhibited multi-step saccades but, in the absence of distractors, FEP did not differ significantly from that of healthy age-matched participants, suggesting unimpaired VSWM in these mild PD patients. Only irrelevant distractors visually identical to the to-be-remembered targets affected FEP accuracy in healthy age-matched participants. By contrast, both identical and visually distinct distractors produced significant increases in inaccuracy of the FEP in patients with PD. This specific VSWM impairment is discussed in relation to theories that posit a role for the basal ganglia in gating the access of stimuli into VSWM.

Effect of saccadic eye movements on postural stability

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The goal of the study was to examine the effect of different visual tasks on postural stability. Ten healthy young adults (25±3 years) participated to the study. Postural control measured by the TechnoConcept® platform has been recorded in Standard Romberg and Tandem Romberg condition during five visual tasks: fixation (simple and with distractors) of a cross, and three different types of horizontal visually-guided saccades of 4° of amplitude: reactive (gap 0 sec), voluntary saccades (overlap 600 sec) and antisaccades. Viewing distance was 114 cm and postural stability was recorded for 25.6 seconds. The surface area of the center of pressure (CoP), the length of trajectory and the mean of speed of the CoP and the frequency analysis of body sways were analyzed. According to previous studies we found that postural control improved in Standard Romberg with respect to the Tandem Romberg position. The postural stability in saccadic tasks improved with respect to the fixation tasks. The new finding was that the antisaccade tasks decreased postural stability compared to other types of saccadic tasks. This result is in line with the U-shaped non linear model described by Lacour et al. [2008, *Clinical Neurophysiology*, 38, 411-421], showing that a secondary task performed during postural task could either increase or decrease postural stability depending on its complexity.

Visual Deficits

Blinks in the blind

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Objectives: Blinks play a key role in the distribution of lachrymal liquid throughout the cornea, thus participating in eye protection and smooth functioning. In sighted individuals, blink occurrence is notably modulated by ongoing visual activity demands. Such a modulation is de facto impossible in blind individuals. In the present study, we investigated blink modulation factors in both congenital and acquired blindness. **Material and Methods:** In the present study, we investigated blink modulation factors in both congenital and acquired blindness. Volunteers performed several cognitive tasks (e.g., verbal fluency, finger labyrinth, counting backwards) as their ocular activity was continuously recorded using the electro-oculogram technique. **Results:** It turned out that the execution of cognitive tasks affected blind participants' blinking activity. Cognitive load was associated with a higher blink number. However, it is worth noting that congenitally blind participants exhibited fewer blinks than their counterparts with acquired blindness, and sometimes no blinking activity at all. **Discussion:** The present study confirms that blink occurrence is influenced by non visual dimensions and reveals a cognitive modulation of blinking activity in blind individuals.

Visual perception and saccadic eye movement characteristics in hemianopic patients

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Saccadic eye movements and perceptual abilities of hemianopic patients, suffering from a loss of the visual field contralateral to a unilateral occipital lesion, were compared to those of matched healthy controls. Participants were asked to detect a visual target briefly displayed at 5° or 8°, in the left or right visual field. Blank trials were interleaved with experimental trials to prevent any response bias. This task was done in three successive sessions: Fixation, Voluntary and Reactive saccades (elicited by Overlap-600ms and Gap-0ms respectively) towards the visual target. According to our preliminary results, visual targets in the blind hemifield evoked saccadic responses. Patients' latencies were longer than those of controls, for both types of saccades. As expected, latencies were longer for voluntary than reactive saccades in controls and in patients but only in their intact hemifield. Saccade accuracy measured by gain seemed relatively correct in both fields, although more variable compared to controls. Detection rates indicated that targets in the blind field were not perceived consciously but still able to generate saccadic eye movements, even in the absence of visual consciousness. We hypothesize that residual visual ability allows target selection and motor programming, despite alterations in saccade parameters.

Attention and eye position interact to destabilize gaze

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When central vision is lost due to retinal disease, observers adopt a new retinal locus in the periphery for fixation and directing gaze (PRL). It has been noted clinically that the stability of gaze declines as a function of the eccentricity of the PRL and it has been argued that this instability may actually reflect a strategy that improves peripheral visual acuity for isolated targets. This instability, however, is correlated with declines in reading performance and visual acuity for crowded targets. Using normally sighted observers and an artificial scotoma paradigm, we examine gaze stability as observers perform a crowded orientation discrimination task in the periphery. When the fovea and attention are congruent, fixation is stable (normal condition). When the fovea is centered and attention is deviated to the periphery, fixation remains stable (eccentric viewing). However, when the fovea is deviated and attention is central, fixation stability is disrupted (clinical condition). We conclude that additional, perhaps head-referenced signals, impact gaze stability and that attentional shifts back to head-center exert a stronger pull on oculomotor control systems. These findings have practical implications for low vision rehabilitation strategies.

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Inhibitory and vector inversion deficits during antisaccades in hemispatial neglect and visual form Agnosia (patient DF)

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Butler et al [2009, *Neuropsychologia*, 47, 2488-2495] reported elevated bilateral error rates in an anti-saccade task in right hemisphere hemispatial neglect patients. Recent evidence has dissociated the inhibitory requirements of this task from the demands of vector inversion and implicated posterior brain regions such as the Intraparietal sulcus in this latter aspect. In study 1 we report how 5 of the patients tested by Butler et al perform in an additional fixation test of inhibitory capacity relative to their pro-saccade and anti-saccade performance. In study 2 we tested patient DF, who has visual form Agnosia. In study 1 we observed bilateral impairments in the anti-saccade task, both in terms of increased error rates and diminished accuracy of landing points, but no evidence of bilateral inhibitory deficits in the fixation task. In study 2 we observed that patient DF was significantly impaired in the accuracy of her saccadic landing points. We interpret the data obtained from the fixation tests as indicative that the patients may be impaired in the vector inversion requirement of the anti-saccade test, and thus provide support for the view that voluntary eye movement generation depends on a large and integrated network of brain structures which includes posterior regions.

Visual search disorders after stroke

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Deficits in visuospatial perception are common after stroke and are associated with a poorer recovery of the activities of daily living. In this study we aim to assess the effect of stroke on visual search tasks involving both local and global features. 10 patients with right hemisphere (RH) stroke, 8 patients with left hemisphere (LH) stroke and 24 healthy participants were included in the study. They performed two visual search tasks that differed in terms of the local and global processing. In half of the trials, the target was present and in the other half, it was absent. We observed that all stroke patients were particularly impaired in the detection of the global figure compared with the controls. Interestingly, performance was also poor in the target-absent trials for the patients, showing more false positive reports (saying the target was present when it was not) in the global task. The RH group had longer reaction times than the LH group on the target-absent trials. These findings suggest that the level of processing of the target affect particularly the search efficiency in stroke patients. These results are of relevance for the design of virtual reality tasks for the rehabilitation of visuospatial deficits.

Reading: Visual & Oculomotor Processes

Effects of word length and orthographic features on initial fixation landing positions

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Previous research has demonstrated that readers use word length and boundary information in targeting saccades into upcoming words while reading. By embedding long (8-9 letters) or short (4-5 letters) target words, which share initial trigram letter sequences, in an identical sentence frame we examined how orthographic information available in the parafovea influences the oculomotor targeting system during normal reading. A gaze-contingent invisible boundary [Rayner, 1975, *Cognitive Psychology*, 7, 65-81] was used to manipulate the parafoveal information available to the reader before direct fixations on the target word. The parafoveal preview was either identical to the target word or a visually similar nonword. The nonword previews contained either orthographically familiar or orthographically irregular initial letter sequences. Critical results demonstrate that lexical status and orthographic features of the parafoveal preview affect initial landing sites. Specifically, orthographically irregular previews prompt landing positions closer to word beginnings than other preview conditions and identical previews lead to initial fixation positions farther into the target than other preview conditions. Interestingly, this pattern was consistent across both long and short words when controlling for target word refixation. These data suggest that lexical processing mediates both temporal and precise spatial aspects of eye movements during normal reading.

Reading Arabic text: Effects of word length on landing positions and fixation durations

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An experiment is presented examining eye movement behaviour during reading of Arabic text (read from right to left). Native speakers of Arabic read single line sentences including critical words that were three, five or seven characters long. Initial sentence frames were identical across the three conditions. Word frequency and predictability were carefully controlled. In contrast to reading of left-to-right languages, and similar to reading of right-to-left Hebrew text [Deutsch & Rayner, 1999, *Language and Cognitive Processes*, 14, 393-421], the preferred viewing position tended to be at the word centre or just right of the word centre. The results indicate that, similar to other languages, parafoveal word length information is used to guide saccade targeting in Arabic. Further analyses examine the effect of word length on fixation probabilities (skipping and refixations) and the effect of word length on fixation durations. The results will be compared to those in other languages and the implications for models of eye movement control during reading will be discussed. In particular, the study helps identify which aspects of the models might generalise to accounting for eye movement behaviour during reading of spaced alphabetic texts read from right to left.

Effect of character size on the launch-site effect during reading: Should we keep on measuring saccades in letters?

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It is established that during reading, saccade amplitude, when measured in letters, does not vary with character size. For this reason, saccadic behaviour is traditionally expressed in letters. However, this tradition only rests on global eye-movement analyses and more precise, word-based analyses have never been performed. Here, we investigated the influence of character size on local eye behaviour through the launch-site effect; this shows that the eyes land further into a word as they come from closer in the line of text. The eye movements of fifteen participants were recorded while they read lines of unrelated words. Font size (.2° and .4°) and the eccentricity of the target word (1-9 character spaces) were manipulated. We fitted the overall distributions of saccades' landing sites, thus considering cases where the eyes landed within and beyond the target-word boundaries. Results revealed a stronger launch-site effect along with a greater skipping probability for small- compared to large-printed words; in the closest launch-site conditions, saccade amplitudes (in letters), were significantly greater for small-printed words. Inconsistent with classical findings and models of eye-movement control in reading, this result suggests that we may need to reconsider the use of letters as a metric of saccadic behaviour.

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Dissociating spatial and letter-based word length effects observed in readers' eye movement patterns

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In previous eye movement research on word length effects, spatial width has been confounded with the number of letters. McDonald unconfounded these factors by rendering all words in sentences in constant spatial width [McDonald, 2006, *Visual Cognition*, 13(1), 89-98]. In the present study, the Arial font with proportional letter spacing was used for varying the number of letters while equating for spatial width, while the Courier font with monospaced letter spacing was used to measure the contribution of spatial width to the observed word length effect. The number of letters in words affected single fixation duration on target words, whereas words' spatial width determined fixation locations in words and the probability of skipping a word. The results support the existence of distinct subsystems for deciding where and when to move eyes in text. The number-of-letters effect obtained in fixation duration may be explained by visual acuity, visual crowding, serial letter processing, or a joint influence of all three factors.

Singular value decomposition is a valid predictor of stroke importance in reading Chinese

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Chinese characters are written in a specific, non-arbitrary stroke order, which may reflect a stroke's importance. Previous research on stroke removal showed that removing the initial strokes from characters made them harder to read than removing the final strokes or the shortest strokes [Yan et al., 2011, *Reading and Writing*, 1-29]. Singular value decomposition (SVD; a method of decomposing the matrix of pixels representing a character in order to degrade it, but retain the most important segments) may be a better way to estimate which elements of a character are most important for identification. In the present study, characters were decomposed into segments (i.e., vertical, horizontal, and diagonal lines) and the importance of each segment's contribution to character configuration was determined by SVD. Subjects read each sentence from the Yan et al. study either with all or 70% of the segments retained. The retained segments were the most important, the least important, or randomly selected. When the most important segments were retained, subjects read as fast as when all were retained. When the least important segments were retained, reading fluency was reduced. The results suggest that SVD is a psychologically valid way to capture Chinese character configuration.

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Do serifs provide an advantage in word recognition and reading?

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Most books/e-books are printed in a serif font and the Publication Manual of the APA (2009) recommends serif fonts when submitting manuscripts. Although serif fonts have been considered easier to read than sans-serif fonts, prior empirical evidence is scarce and not conclusive. Here we analyzed whether serifs (i.e., the small features at the end of strokes) play a role in lexical access by comparing words from the same family either with a serif font or with a sans-serif font. Experiment 1 showed a very small advantage for words written in a sans-serif font in a lexical decision task [Moret-Tatay & Perea, in press, *Journal of Cognitive Psychology*]. This finding was replicated in a normal silent reading experiment in which the participants' eye movements were monitored (Experiment 2). In sum, serifs do not facilitate the process of visual-word identification; instead, the presence of serifs may (if anything) hinder lexical access.

Pupilometric and font effects in a lexical decision task

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The primary aim of this study was to determine whether font type (serif vs. sans serif) affected performance in a lexical decision task under low-contrast conditions. A secondary aim was to explore possible pupilometric effects of the task. Subjects were required to fixate the centre of a computer display after which a word or an orthographically regular non-word was presented 1.5 degrees to the right of centre. The word could be in either a serif or sans-serif font (i.e., Times New Roman or Arial). The subjects' task (eight female and eight male) was to make a rapid lexical decision. During a practice period, the contrast level of the display was set separately for each individual to give approximately 50% overall accuracy. Overall performance accuracy was significantly greater for Arial as opposed to Times New Roman. There were significant pupilometric effects for word frequency, word length, and font type across a number of pupilometric parameters. Average pupil dilation tended to vary more as a function of visual features of the task such as font type and word length, whereas latency to peak dilation was sensitive to more cognitive task aspects such as word frequency.

The effect of contrast on binocular coordination while reading

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The investigation of binocular coordination during reading has shown inconsistent findings: Nuthmann and Kliegl [2009, *Journal of Vision*, 9(5), 1-28] found vergence disparities in front of the monitor; Liversedge et al. [2006, *Vision Research*, 46, 2363-2374] noticed the disparities being located predominantly behind it. A possible reason can be the background brightness: Nuthmann presented black sentences on a bright background (positive contrast), whereas Liversedge presented bright sentences on a black background (negative contrast). Inferentially, we think, that a brighter background seems to be closer to the observer than a dark background. We investigated the effect of the background brightness and calibration on vergence during reading, in an experiment consisting on 84 sentences displayed on two media (paper and screen) with two calibration conditions (white and black) and two backgrounds (light and dark). We found that when white calibration on a dark background was used fixation was behind the display surface. The contrary, fixation on front of the display surface, was found with a black calibration on a light background. The effect of the medium (paper or screen) was marginal.

Characterizing binocular eye-movements in reading in esotropic Duane's Syndrome

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We present a case-study of the eye-movements in reading of an individual with esotropic Duane's Syndrome, which involves an inability to move one of the eyes away from the nose (abduction), but typically near normal adduction and intermittent diplopia. The participant read some 5000 words of English text, consisting of slightly modified newspaper stories, and their eye-movements were recorded binocularly, using a monocular calibration procedure. The eye-tracking record shows the unaffected right eye moving across the lines of text on both left and right halves of the screen, while the affected left eye only moves in the right - but not the left - half of the screen during reading. The left eye moves concordantly with the right eye in the right half of the screen but only makes small and spatially unrelated (but temporally related) saccades when the right eye fixates text on the left. The participant read slowly and reported no diplopia. These data reveal the constraints on uptake of visual information by Duane's Syndrome readers, and the flexibility required when the unaffected eye fixates in the affected hemifield.

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The accurate diagnosis of dyslexia by erratic eye movements (ophthalmokinesis) by non-verbal tasks

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Dyslexia is a specific learning disability in reading and in writing, of neurobiological and mainly hereditary origin. The results of previous studies indicated that eye movement recordings, taken during non-reading tasks, can accurately differentiate dyslexics from matched normal readers [Pavlidis, 1981, *Neuropsychologia*, 19, 57-64; Pavlidis, 1990, *Neurology, Neuropsychology and Genetics*, Vol. I. Chichester, J. Wiley & Sons]. Methodology: All data were automatically and accurately collected and analysed by the photo-electric hardware and software developed by the author. Participants: 149 boys (87 dyslexics and 62 normal readers) took part in the study. They ranged in age from 10 years to 18 years 9 months and they were drawn from USA private, mainly residential schools. Stimuli: They followed with their eyes, moving and stationary (saccadic and pursuit) light spots displayed on a monitor. Many of the tasks simulated the non-verbal and sequential aspects of reading. Results: In contrast to normal readers' consistent and regular eye movements, dyslexics frequently exhibited highly variable and sometimes erratic eye movements, which were statistically significantly worse ($p < 0.000$). On the basis of the ophthalmokinetic characteristics, 90.5% of dyslexics were correctly classified, as were 86.7% of the matched normal controls. This is one of the highest success rates of any neurophysiological test. Discussion: The results replicated our previous study conducted in England on a completely different population. As it is not based on reading or writing and dyslexia exists from birth, it can be used from preschool age onwards for the objective biological prognosis and later for the diagnosis of dyslexia irrespective of educational opportunities, psycho-social background, intellectual factors or language spoken. It offers dyslexics the hope for more effective treatment and the avoidance of the secondary psychological problems that usually follow the school failure.

Reading: Word Recognition

Vernacular "Transcriptions" vs. Standard Orthographies

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Younger readers of non-transparent (also: inconsistent) orthographies show increased use of vernacular "transcriptions", a style of writing that focuses on phonetic detail and ignores orthographic rules of the standard language. Writing in such vernacular "transcriptions" appears predominantly in text messages, emails and chat rooms. Although German is considered a fairly consistent orthography, with a phoneme grapheme correspondence of up to 68%, vernacular "transcriptions" have become popular among younger readers. But how is the vernacular "transcription" processed? We argue that readers of dialect orthographies are not faster in processing the content of a written vernacular conversation than in processing the same text in standard orthography. In our eye-tracking study we have presented younger readers, who frequently use a vernacular "transcription", with texts in a vernacular orthography, that their peers have rated "typical" and "highly legible". We will show data from two experiments that compared subjects' reading eye movements of vernacular "transcriptions" with subjects' reading eye movements of similar texts spelt in standard orthography. Subjects claim that the use of a vernacular orthography enhances quicker reading and facilitates personal communication. In the discussion of our eyetracking data, we will show what really happens when vernacular "transcriptions" are processed.

Reading transposed text: Effects of transposed letter distance and consonant-vowel status on eye movements

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Readers are often able to successfully identify words in which the positions of letters are altered within the word - transposed text. However, recent research from sentence reading studies has shown that there is a cost associated with reading text in which the order of letters is altered. We conducted two eye movement experiments to investigate the flexibility of letter-position encoding in word identification during reading. In Experiment 1, we manipulated the distance between transposed letters (ligament vs. liagment vs. limagent vs. lieamgnt). Reading times increased with the distance between transposed letters, and the effect sizes support open-bigram models of visual word identification. In Experiment 2, we manipulated whether the transposed letters were two consonants, two vowels, or one of each (ssytem vs. faecture vs. fromat). CV transpositions were the most disruptive, while VV transpositions were least so. These data support the argument that consonants are encoded earlier/ faster, and less flexibly than vowels during lexical identification.

Effect of frequency on eye movements in reading and visual search

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Studies have demonstrated that the effect of word frequency on eye movements is robust when participants are reading for comprehension or proof-reading but not when they are scanning text for a target word [Kaakinen & Hyöna, 2010, *Journal of Experimental Psychology: Learning, Memory & Cognition*, 36, 1561-1566; Rayner & Fischer, 1996, *Perception & Psychophysics*, 58(5), 734-747; Rayner & Raney, 1996, *Psychonomic Bulletin & Review*, 3(2), 245-248]. As an extension to these studies, we compared eye-movement behavior on fully-crossed high- and low-frequency adjective-noun pairs embedded in paragraphs when participants were reading vs. engaged in one of three visual search tasks: scanning for a target word with an asterisk (e.g., "h*rse"), a word containing the letter "q" (e.g., "quilt"), or a word rhyming with "blue" (e.g., "shoe"). The results demonstrate that eye-movement measures are affected by frequency in the tasks requiring in-depth processing, such as reading and rhyme-judgment, but not in shallow-processing tasks like asterisk-detection. In addition, we report task-dependent analyses investigating spillover (i.e., the effect of the adjective frequency on the processing of the noun) and any parafovea-on-foveal effects (i.e., the effect of the noun frequency on the processing of the preceding adjective). Results suggest that the degree to which attention is allocated in a serial versus parallel manner is modulated by task demands.

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The effect of word position and word predictability in fast and slow readers

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The study assessed whether the position of a word and its predictability in sentences exert differential effects in fast and slow readers during silent reading of the Potsdam sentence corpus. In correspondence with a recent study by Kuperman et al. [2010, *Quarterly Journal of Experimental Psychology*, 63(9), 1838-57], the fast readers exhibited increasingly longer fixation durations for words towards the end of the sentence. This effect was absent in the group of the slow readers. Word predictability had an effect in both groups with shorter fixation and gaze durations for predictable compared to unpredictable words, but this effect was much stronger in the slow readers. Furthermore, both groups exhibited prolonged fixation durations on words preceding predictable words compared to words preceding unpredictable ones and this effect was of equal size in both groups. In marked contrast to the fast readers, the slow readers skipped even highly predictable words only rarely, despite the similar effect of the predictability of upcoming words in both groups. These findings will be discussed in relation to contemporary models of eye movement control during reading.

Time course of lexical and semantic effects on eye movements in reading

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Eye movements during reading are influenced by lexical and semantic processes as exemplified in word-frequency and word-predictability effects. Here, we estimated their time course while controlling for word length and parafoveal preview. The eye movements of 44 participants were recorded during the reading of 244 sentences where a target word of variable frequency and length was made predictable or not by changing a preceding prime word. Different indexes of eye behavior in the vicinity of the target word were analyzed. Results showed an effect of word frequency on the likelihood of skipping short words, and also of word predictability for high-frequency short words, mainly for close-launch-sites. Frequency and predictability interacted for first fixation duration on long words; the predictability effect was greater for high- than low-frequency words. Further analyses revealed that the word-frequency effect emerged no earlier during a fixation than the word-predictability effect. In addition, the onset time of the word-predictability effect was delayed for low-frequency words, and in close-launch-site cases. These findings suggest that word predictability may intervene during lexical access and that the study of the interplay of visual and language-related variables provides a better estimate of the time course of lexical and semantic processes.

We are grateful to Clémentine Thonnot-Mensier for her help in data collection. This work was supported by a French-German ANR-DFG grant (#ANR-10-FRAL-009-01)

How fast can predictability influence word skipping during reading?

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In an eye-tracking experiment during reading, the extent to which a target word was predictable from the preceding context was varied. In the first two conditions, the target word was embedded in the same carrier sentence but the preceding sentence made the target word either predictable or unpredictable. The third condition was identical to the unpredictable condition but for the word preceding the target word which constrained the identity of the target word rendering it highly predictable. The two predictable conditions were matched on sentence completion ratio. This design allowed us to examine whether contextual predictability needs to gradually build up over the preceding context to have maximal impact on increasing word skipping or whether constraint exclusively originating from word n-1 is fast enough to have a similar impact. Preliminary results replicate strong predictability effects on word skipping (and fixation times) when predictability originates from before the carrier sentence. Numerically smaller effects on skipping were observed for the n-1 constraining condition and limited to those trials when word n was very short, probably due to higher visual acuity for short words. Results indicate that predictability needs to gradually build up to have maximal impact on skipping rates.

Word frequency effects during reading: Binocular fixations and the distribution of fixation durations

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An experiment is presented examining the effects of word frequency on binocular eye movement behaviour during reading. Eye movements were recorded using an EyeLink 1000 eye-tracker; text was presented in black on a light background in a lit room. Reading times were significantly longer for low compared to medium and medium compared to high frequency words. Low frequency words were significantly more likely to be refixated than medium and high frequency words. Word frequency also influenced the probability of word skipping: skipping probabilities were significantly higher for high compared to medium and medium compared to low frequency words. First fixation positions on the critical word were significantly influenced by eye, with the left eye significantly to the right of the right eye. We consider effects of word frequency on first fixation and gaze duration distributions (in terms of differences in the mean of the normal component of the *ex-Gaussian* distribution and the degree of skew). The findings have important implications for models of eye movement control during reading, especially in relation to the binocular data and effects of word frequency on fixation probabilities and durations. Implications for saccade contingent change methodologies will also be discussed.

The processing of word class ambiguous words

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Word class ambiguous words are words which can appear as a verb or a noun, depending on the context they are presented in (e.g., to race or the race). Within the English language there are numerous biased word class ambiguous words where the verb or noun version of the word is more frequent than the other. In the present eye-tracking experiment the effect of word-class frequency on the processing of biased word class ambiguous words was investigated. Two types were distinguished: N>V (noun form more frequent than verb form) or N<V (verb form more frequent). The word class ambiguous words were presented unambiguously either as a verb or a noun in short sentences. A significant effect of word-class frequency was found both in early and late processing measures for the N<V condition, with faster processing of the word when it appeared as a verb compared to when it was presented as a noun. In contrast, no significant effects were observed for the N>V condition. These results suggest a processing advantage associated with the verb form of word class ambiguous words [contra Gentner, 1981, *Cognition and Brain Theory*, 4, 161-178].

Exploring the relationship between literal and figurative meanings when reading four-character Chinese idioms

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Four-character idioms are widely used in Chinese writing system. How the idioms are processed? The "Hybrid" theory [Cutting & Bock, 1997, *Memory & Cognition*, 57-71] proposes that lemmas associated with the simple-lemma of the idiom are processed prior to the so-called "super-lemma" that represents the idiomatic phrase as a whole. The "Super" theory [Sprenger et al., 2006, *Memory and Language*, 161-184] proposes that simple lemmas and super lemmas are activated more or less simultaneously. The present study investigated the time course of the semantic processing of the simple-lemma and the super-lemma by a priming experiment. 39 subjects read 36 prime and idiom-embedded sentences. There are three prime conditions: unrelated, literal, or figurative. The results showed the total viewing times on the target (T) under the figurative condition was significantly shorter than that under the unrelated condition. The literal prime caused significantly longer gaze durations on T+1 than the other two conditions did. Our results suggest that the Super model rather than the Hybrid model better accounts for the data. The Super model cannot fully account for the inhibitory effect of the literal prime. Some modifications to the Super model may be needed.

Multiple models and multiple perspectives approaches in modelling eye-movements in reading

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What is the relationship between the eight published, implemented models of eye-movements (EMs) in reading? Arguably, they resemble the "Multiple Models" paradigm in the philosophy of science: collectively they typically provide more information than each does individually (e.g., E-Z Reader and SWIFT together define the envelope for research on parallel versus serial processing.), and they peacefully co-exist. Further, EM modelling resembles the strategy of abstraction [Levins, 2006, *Biology and Philosophy*, 21, 741-755] in which each model specifies something of the ordered relations between the entities in the domain, by providing a view of the domain from a different perspective (defined across "extent", "vantage point", and "generalizability"). However, it is unclear how many models are required to approach a comprehensive picture of reading. Deeper problems are that this approach (a) cannot produce a particular research program that can be continually improved in detail, and (b) does not produce a single, deep explanation of the essence of the processing. An answer is suggested based on the ontological status of the entities in the models, which can be universals of two types, "abstract" or "concrete", differing with respect to philosophical realism.

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Reading: Sentence & Text Processes

Sentence integration / social cognition interaction in the Hungarian language: Preliminary findings

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Preliminary findings are reported from a psycholinguistic study using eye-tracking methodology, with two aims: (1) to explore sentence integration processes for the first time in Hungarian readers; (2) to test if integration of mental state descriptions into sentence meanings involves specific processes. Participants were 43 native speakers of Hungarian. They read 150 sentences (50 target, 50 control, 50 filler) from the screen of a desktop-mounted 120 Hz binocular eye-tracker. Among target sentences 10 were garden-path, 10 syntactically ambiguous, 10 syntactically erroneous, 10 semantically ambiguous, 10 semantically erroneous. In half of the sentences with semantic anomalies mental state descriptions were ambiguous/erroneous. Control sentences were not-anomalous analogies of target sentences. Fillers were non-anomalous sentences. The key dependent variable was number of regressive saccades. Findings show that (1) sentence integration processes in Hungarian also lead to regressive eye movements in case of syntactic anomalies. As a genuinely new finding, (2) we found that regressive eye movements are evoked specifically by semantic anomalies in the mental state domain, suggesting that cognitive processes presumably dedicated to mental state understanding play key on-line role in sentence integration. (Ongoing) further studies should confirm these findings and clarify the nature of specific cognition-language interplay they suggest.

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Online pronoun resolution during Chinese narrative comprehension: An eye tracking study

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Pronoun resolution is important for readers to build a coherent mental representation. Like most other languages, the written form of the third-person pronouns is different for male and female (i.e.,_/_) in Chinese. To investigate the effects of order-of-mention (first-mention and second-mention) and gender cue (he/she) on pronoun resolution, we recruited 31 college students in southern Taiwan and a 2 X 2 design was adopted. Each trial had two sentences. The first sentence had two characters of different genders, and the second sentence began with a pronoun as the subject, referring to one of characters in the first sentence. Participants read in a self-paced manner and their eye movements were recorded. The results showed that the first sentence received more regressive fixation counts when the pronoun referred to the second-mentioned character than the first one. Also, readers had shorter rereading time on the first sentence when the pronoun referred to the first-mentioned character of the first sentence. However, gender cues did not produce any different patterns. Our study reveals that Chinese readers had a first-mention advantage for pronoun resolution.

Taking a second or third look at symbolic but not at literal haikus: An eye-tracking study

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a bitter rain
- two silences beneath
the one umbrella

Is the connotative meaning of a text readily available or is it accessed only after re-examining a text? Thirty-one English native speakers (10 male, mean age 21) read 24 haiku, 12 in their original/symbolic version and 12 in a version in which the most symbolic word (the keyword "bitter" in the example above) was replaced by a more literal word ("loud"), reducing the text's symbolic purport. Participants' eye movements were recorded using the eye-tracker EyeLink 1000. The effect of the word substitution was measured globally, by comparing the total reading times for the two haiku types, and locally, by examining first pass duration and dwell time on a word closely connected to the keyword (the referent, "silences") and on the last word ("umbrella"), as this might show wrap-up processes. First pass durations showed no effects of the substitution. However, total reading time and dwell time on both the referent and the last-word regions were significantly longer for haiku with the original keyword than for haiku with the altered keyword. These findings suggest that the texts' connotative meaning was not available immediately but only through re-reading of the texts.

When lexical access for ambiguous words can be reordered: Reducing the subordinate bias effect via a repetition paradigm

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Readers experience processing difficulties when reading biased homographs preceded by subordinate biasing contexts. According to the Reordered Access Model [Duffy et al., 1988, *Journal of Memory and Language*, 27, 429-446] this is the result of competition between the dominant meaning and the context-instantiated subordinate meaning upon reaching activation simultaneously. Attempts to overcome this processing deficit by further instantiating the subordinate meaning have often failed to eliminate the subordinate bias effect, upholding the conclusion that lexical access is exhaustive, but not selective. The present study examined the processing of biased homographs preceded by sentence contexts that instantiated the subordinate meaning. We varied whether this preceding context contained a prior instance of the homograph or a control word/phrase. Having previously encountered the homograph in its subordinate meaning earlier in the sentence reduced the subordinate bias effect for the subsequent encounter, while simply instantiating the subordinate meaning did not. We compared these reductions in reading times to conditions in which the dominant meaning was instantiated by a preceding context that included either the homograph or a control word/phrase in order to verify that the reductions observed in the subordinate cases were not simply a benefit of recent lexical access through repetition.

The on-line sentence processing of causal and anaphoric inferences

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Making causal connections and using referring expressions plays a fundamental role in understanding discourse by linking successive utterances to form a coherent representation. The aim of the research was to explore the on-line causal and anaphoric inferences in reading Chinese text. University students in Taiwan ($n = 30$) read 36 experimental short texts and 18 fillers in randomized order. Each text had two sentences describing two characters engaging in an event in the first sentence, and a consequence or another event in the second. A question followed to probe their anaphoric or causal resolution. Causality (strong or weak) and anaphoric resolutions (overt or zero pronoun) in texts were manipulated and participants' responses were recorded by an eye tracker. The results revealed participants generated significant differences in causality, whereas no significant effect in anaphor variables was found. Participants invested more processing time and counts for texts with weak than strong causal connections. On the other hand, Chinese reader's overall comprehension was not affected by the removal of anaphors. The results suggest when reading texts with strong causal connections, readers could build a more effective mental model. It could be explained causality plays the stronger role in reading comprehension than anaphor does.

Scalar implicatures and eye movements: When are the expectations of relevance met?

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Someone asks you: "Did you enjoy the conference?" Your answer: "Some talks were interesting." This implies that you did not find all talks interesting. This inference from "some" to "not all" is an intensely studied phenomenon in linguistics, called scalar implicature. It is a conversational inference that presupposes ordering of elements on a scale, such as <some, all>. If a speaker uses the weaker term on the scale, the hearer infers that the stronger element is not the case. A question that has troubled researchers for a long time is whether scalar implicatures are computed by default (neo-Gricean view) or require an effortful process and stop when participants' expectations of relevance are met (Relevance Theorist view). With this experiment we try to elucidate the debate by investigating participants' eye movements when evaluating statements including scalar implicatures about circles containing dots. The ratio of filler items and view time were manipulated because previous research had shown that these influence participants' judgments. Example: "Some of the circles contain dots": do participants make a decision on the basis of seeing one or two circles containing dots or do they go on and look at each circle before coming to a conclusion?

Information leakage during reading

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Offline experiments [McKenzie & Nelson, 2003, *Psychonomic Bulletin and Review*, 10(3), 592-602; Teigen & Karevold, 2005, *Journal of Behavioural Decision Making*, 18, 1-18] indicate that readers draw sophisticated inferences from logically equivalent frames. If a glass is described as 'half full' readers may infer that the glass was previously empty rather than full. If a project is described as '50% completed' readers may infer that the work is ahead of rather than behind schedule. In two experiments we examine if similar inferences are made online. Materials for an eye-tracking study were constructed based on those from offline tasks. Participants read passages containing logically equivalent frames 'half full' or 'half empty' in Experiment 1, and 'half of the time is over' or 'half of the time is left' in Experiment 2. These frames were followed by an inference which was consistent or inconsistent with results of offline studies. Results showed that during reading participants did not make the same inferences seen in offline tasks. Regardless of frame the more frequent or common inference, a full glass or a team required to speed up, was read more easily. It is suggested that this result is driven by word related factors e.g. markedness.

Predicting states of mindless reading from eye movement recordings

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It sometimes happens that we finish reading a page of text just to realize that we have no idea what we just read. During these episodes of mindless reading our mind is elsewhere yet the eyes still move across the text. Recent progress in understanding this phenomenon has been achieved by using subjective self-report measures. Here, we present an error detection approach to measure mindless reading behaviorally via different error types. Under experimental conditions that are likely to induce mindless reading, we found that the deeper the processing required for detecting an error in the text, the less likely subjects were to notice it. Furthermore, mindless reading was associated with shortened fixation times on phrase- and sentence-final words and a reduced word-frequency effect on fixation times for long words. We demonstrate that fixation times on long words predict the detection of lexical errors, yielding an objective online-indicator for mindless reading. These findings suggest that episodes of mindless reading can be measured in a signal detection analysis. The results provide new insights into the cognitive control of eye movements and present a first step toward a technology to ameliorate the negative consequences of mindless reading in everyday life and cognitive experiments.

The effects of mind-wandering and working memory capacity on text comprehension

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Mindless reading occurs when a reader's eyes continue moving across the printed page with little or no comprehension of the text being "read" [Reichle et al., 2010, *Psychological Science*, 21, 1300-1310]. The present study examined the eye movements of 100 participants reading a novel with instructions to indicate all occurrences of mindless-reading. Relative to normal reading, fixations during mindless reading were longer in duration and less affected by lexical variables. Although the tendency to lapse into mindless reading was not related to participants' working memory capacity, those participants who lapsed into mindless reading more often also demonstrated poorer comprehension of the text. These two findings strongly suggest that text difficulty per se (i.e., difficulty associated with comprehension, as modulated by differences in working memory capacity) are not affecting the propensity to lapse into mindless reading, but that mindless reading is causing comprehension difficulty.

Cognition & Expertise

Teachers' perception of students' classroom behaviors: An eye movement study

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Perception of classroom teaching scenes is crucial to the expertise on teaching. Previous studies have shown that expert teachers and novices differ in perception, processing and understanding of classroom teaching activities. However, these studies were limited by the use of surveys, questionnaires, and observations, and failed to provide a direct data in authentic situations. In this study, a classroom teaching video clip was constructed as a stimulus. Two types of student behaviors were manipulated. One was a typical student's classroom behavior in which a student was waiting for the teacher's permission with her hand in the air. The other was a problem behavior in which a student was playing with her pencil and was not engaged in lecture listening. Tobii Eye Tracker 1750 was used to record the eye movements. Results revealed that teaching experience can affect visual classroom information. Expert teachers and experienced teachers could equally distribute their fixations to the typical behavior and the problem behavior. However, for the novices, they were only attracted by the typical behavior. These findings shed a new light on the understanding of the cognitive processes of expert teachers and novice teachers.

The investigation of teachers' looking behavior: Developing a methodology for selecting scenes in real-life videos

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The first aim of this study pertains to the investigation of differences between novice and experienced teachers' looking behavior when observing pupils in a classroom. However, the stimuli are dynamic real-life video-fragments. Therefore, the second aim pertains to the development and testing of a methodology using participant-generated timestamps to demarcate single classroom events appropriate for eye-tracking analysis. Teachers watched eight video-fragments of classrooms recorded from the teacher's perspective. They were instructed to press a button that recorded timestamps whenever they would intervene in real-life. Stimulated recall data was collected for each timestamp. Scenes for eye-tracking analysis were selected by identifying clusters of timestamps using three stringent criteria (e.g. whether enough timestamps (>1.50 timestamps/second) were made by enough participants). The stringency ensured that only the most salient events were selected. Selected scenes show results with clear differences, e.g.: experienced teachers have .80 times shorter, and 1.50 times more fixations; experienced teachers distribute their visual attention better, they spend at most 36% of their total time on one pupil. This is in contrast to the 55% of the time spent by novices, at the expense of other pupils. The data and methodology will be presented in more detail than the available space for this proposal permits.

Strategic IQ: Analogical reasoning in individuals with high fluid intelligence is mediated by eye movement strategies

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High fluid intelligence permits maximizing performance in cognitive tasks by quickly adapting to task demands. However, subtle advantages might already occur during strategic information acquisition. The contribution of strategy deployment to behavioral advantages associated with high fluid intelligence has been neglected in the literature. We, therefore, administered geometric analogical reasoning tasks and compared eye movement strategies of participants with high fluid intelligence (hi-fluIQ) to those with average fluid intelligence (ave-fluIQ). We distinguished between two visual information acquisition strategies: *Constructive Matching*, defined as employing the minimal number of gaze alternations between task elements, and *Response Elimination*, defined by recurring gaze alternations. *Constructive Matching* was the more effective strategy for both groups in terms of behavioral performance. Hi-fluIQ applied *Constructive Matching* more frequently resulting in superior behavioral performance compared to ave-fluIQ. In addition, when applying *Response Elimination*, error rate was elevated in ave-fluIQ compared to hi-fluIQ. Our results confirm that employing *Constructive Matching* in geometric analogical reasoning is associated with more efficient task performance. Thus, we conclude that hi-fluIQ are more efficient in their strategic information acquisition than ave-fluIQ. This implies that fluid intelligence facilitates deployment of effective solution strategies in cognitively demanding tasks.

Number line estimation - is there a link between eye movements, performance, and mathematical aptitude?

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Eye-tracking is still rarely used in numerical cognition research [but see Moeller et al., 2009, *Cognitive Development*, 24, 371-386]. Here we wondered whether tracking eye-movements could provide new insights into the processing mechanisms underlying number line estimation and whether eye-movements are linked to mathematical aptitude. Fifty-five University students performed a computer-based number line estimation task with touch screen to indicate number positions, while their eye-movements were recorded. Number lines ranged from 0-to-100 and from 0-to-10 and were presented in a familiar (left-to-right; top-to-bottom) or unfamiliar orientation (right-to-left; bottom-to-top). Even though participants had no instructions to fixate number positions on the line, touch accuracy and accompanying fixation accuracy correlated for all 0-to-10 lines and for familiar but not unfamiliar 0-to-100 lines. Moreover, for horizontal familiar 0-to-100 lines, fixation accuracy increased with mathematical aptitude, while touch accuracy only showed a similar trend. Neither number of saccades nor median fixation duration correlated with number line estimation accuracy, making general differences in exploration strategy unlikely. The data suggest that compared with behavioural data eye-movements might be a more sensitive measure of an individual's mental number representation; thus, making eye-tracking an exciting tool for numerical cognition research.

Verification of effect of Care Recording System based on eye tracking

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In the current aged society, the need for high-quality care tailored to individual elderly people is increased. For that, the condition of the recipients and their needs must be grasped in detail, but it is too heavy a burden for them. Therefore we developed a portable Care Recording System in order to record daily statuses of patients easily, even during caregiving. By using this system, it was expected that each caregiver can pay more attention to their charges. In order to verify that effect, the eye movements and behavior of six caregivers were recorded during caregiving in the living room of a care facility. The result showed a clear difference between before and after introducing the system. Before using the system, caregivers looked at every patient evenly, whereas after using the system, they looked at patients at a higher care level more frequently than patients at a lower care level. Furthermore, while they dealt with one patient, they often turned their gaze to the other patients in order to watch their conditions. In fact, caregivers realized that they watched patients more carefully. Eye tracking data showed that our Care Recording System is possible to make caregivers to pay more attention to patients requiring more care.

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How do expert caregivers make a decision? An analysis based on eye tracking

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The number of elderly people with dementia requiring care in Japan is expected to reach 2.5 million by 2015. Accordingly, Japan faces a crucial shortage of caregivers. To solve this problem, efficient and effective transfer of expert caregivers' know-how is necessary. In caregiving, it is difficult to make a decision on what care to provide, and decision making is done based on observation of the patients. Therefore, it is expected that eye tracking data can give some suggestion on knowledge in care. In this study, the eye movements and behavior of caregivers were recorded while they were working in a care facility and compared between experts and novices. The results showed that expert caregivers carefully watched patients carefully with whom they communicated. They especially paid attention to the patient's face and mouth while they helped with eating. At the same time, the expert caregivers often glanced at other patients. Such tendency was also observed while expert caregivers worked on tasks which require no communication with caretakers. On the other hand, novice caregivers focused on patients for whom they were caring and glanced at other patients less frequently. Results suggest that expert caregivers paid attention widely and flexibly to individual patients in order to respond to their demands.

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Web Search & Applied

Visual scanning of commercial websites as a function of content complexity

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The main aim of this work was to study the role of content complexity in visual scanning of websites. Complexity of sites was defined using criteria such as: amount of text, menus, and images. Websites were also rated emotionally and, moreover, several instructions were given to the participants in order to manipulate the level of involvement during the scanning. Eye movements of 52 participants (38 women and 14 men) were recorded while looking at 4 commercial websites of two categories (food industry vs. interior decorating) and two levels of content complexity (simple vs. complex). Emotional rating of websites was evaluated by means of the SAM (Self-Assessment Manikin) for the dimensions of: valence, activation and power. Results indicated that the level of content complexity had an effect on the scanning patterns, but only in the food industry category. On the contrary, the emotional dimension of website was not related to the visual exploration. Finally, instructions exerted influence on the number of fixations.

Eye tracking in marketing research: A scientific approach

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The aim of the study was to investigate the relationships between the eye tracking measures and the emotional, motivational, motivational, and cognitive processes. Eye tracking has become very popular in marketing research. However, it is unclear how the data acquired during the registration should be reliably interpreted. There exists little published research on this topic, while many of the indexes, such as gaze duration or fixation duration, have different, often conflicting interpretations in scientific literature (e.g., whether longer fixations mean that the AOI is interesting or unclear). In the study, apart from the eye tracking data, physiological responses and questionnaire measures concerning emotional reactions and memory were recorded. In the first study the material consisted of standardized visual emotional stimuli, while in the second study marketing materials were used. The results are discussed in the context of existing research on visual and cognitive processing. It is hoped that the results will allow for a better understanding of the investigated relationships, and that their application in marketing studies will lead to the further development of this method in the consumer research area.

Sex differences in e-navigation

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Tasks that require fine motor ability typically favour females, whereas tasks requiring gross motor ability usually favour males [Kimura, 1999, *Sex and cognition*. MIT Press]. Part of males' advantage for gross motor movements might stem from a higher oculomotor precision in smooth pursuit [Wilner & Nakayama, 2006, *Journal of Vision*, 6(6), 94]. Additionally, males and females search and treat information in electronic environments differently as evident from differences in scan paths [i.e. Roy & Chi, 2003, *Journal of Educational Computing Research*, 29(3), 335 - 348]. Sex differences seem to impact males' and females' everyday e-navigation differently, sometimes benefitting one sex more than the other. In this study we explore the biomechanical and cognitive underpinnings of these sex differences. We will examine eye and mouse movements using purely perceptual tasks and everyday computer tasks. To disentangle biomechanical and cognitive causes of sex differences, we will contrast performance and navigation across these tasks. Additionally, an eye-hand coordination measure based on a vector comparison method [cf. Jarodzka et al., 2010, In C. Morimoto & H. Instance (Eds.), pp. 307-314] will be developed to test for differences in cognitive load and the allocation of attention between the sexes. We expect to find differences in both navigation and performance that have both biomechanical and cognitive origins.

Effect of expertise on programmers' gaze patterns during code understanding

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Program understanding is at the heart of many software engineering tasks. We present results from an study on program understanding involving 54 individuals. Subjects had to describe the functionality of ten small Java programs and two long programs. We rely on the structure of the programs that subjects look at to compute indicators that reflect different code reading strategies (following the control flow versus following variables slices) and categories of elements being looked at. In general, subjects spend much more time looking at expressions compared to other elements (like keywords, control structures, method signatures). More specifically, experts look less than novices at structural elements (type names and keywords) which are not essential when understanding the functionality of the code. Experts look more than novices at the predicates of conditional statements and the expressions (e.g. $v \neq 10$), which contain the gist of the programs. We also show that the temporal pattern of gaze differs with expertise. Experts start by looking at a larger portion of the code and then focus on some smaller regions while novices tend to not have this first global scanning pattern. Also experts look sooner at the essence of the program (mainly expressions) than do novices.

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Older adults' health knowledge and comprehension processes of multimedia health information

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We investigated older adults' comprehension of multimedia information (text accompanied by pictures) about hypertension, using eye tracking to measure comprehension processes. Consistent with previous findings, older adults with more health knowledge better understood the presented health-related passages. Of most interest was whether this advantage was rooted in different strategies of information processing. To find out, we partitioned participants' fixation data into phases based on the re-reading and multimedia literatures. During their first pass through the passage, older adults with more health knowledge were found to spend more time than those with less knowledge on reading text than on viewing pictures. However, this situation was reversed after the first pass, as the proportion of time spent reading text was now negatively correlated with hypertension knowledge. In other words, more knowledgeable participants spent less post-first-pass time reading and more viewing pictures. These differences between high- and low-knowledge group strategies may in part be due to differences in the creation of situation models across processing phases. Our findings suggest that better comprehension of multimedia health information depends on a particular strategy (reading followed by a picture-based wrap-up), which may suggest design approaches for more optimal arrangement of texts and pictures in multimedia content.

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An investigation of the effect of task, content and visualization on graph comprehension: A fNIR and eye tracking study

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This study aims to investigate the effect of different graph designs (round/linear) and different tasks (trend assessment/discrete comparison) on trend and cyclic event comprehension. The results of a previous experiment indicated that cyclic events have another dimension (cyclicality) as compared to trend events. Linear graphs, however, are inefficient representations for conveying this semantic dimension. This characteristic of cyclic events can effectively be accommodated by sphericity of the round graph. In order to substantiate the differences observed among participants' accuracy of responses across different graph types, a follow-up study has been conducted by incorporating functional near-infrared (fNIR) optical brain imaging tool as an additional data collection modality. fNIR is used to investigate brain activity elicited by cognitive processes underlying graph comprehension in dorsolateral and inferior-frontal cortex, which allows real-time monitoring of changes in cognitive workload induced by different graph types. Synchronous eye tracking and fNIR recording has been made with 6 subjects. A significant difference was found in number of errors as an indicator about efficiency of round graph visualization. Moreover, a significant difference was found in fixation count, fixation duration and mean oxygenation values of participants across task types.

Expertise development for a visual task: Eye movements, verbal reports, and spatial abilities in air traffic control

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Operators of air traffic control (ATC) stations deal with complex visualizations involving many airplanes that must be navigated towards one airport. Making decisions based on visualizations requires domain knowledge and perceptual skills, like efficient visual search of critical airplane compositions, their quick and correct interpretations, and the appropriate decisions. This study compared 33 participants of three different expertise levels in interpreting ATC stimuli to investigate the role of perceptual ATC skills. ATC performance, eye movements, verbal reports, and spatial abilities were recorded for three task difficulties. Results show that novices performed tasks slower than intermediates ($p=.01$) and experts ($p<.01$), while investing more mental effort in easy tasks than intermediates ($p=.06$) and experts ($p=.05$). Eye tracking data revealed that participants did not differ in total viewing time on airplanes, but in total viewing time of the airport position. Novices looked significantly longer at this area than intermediates ($p<.01$) and experts ($p<.01$). Interestingly, we found no significant relation of spatial abilities and expertise in ATC. These results indicate that experts in ATC do not develop higher spatial abilities, but perform faster while investing less mental effort in easy ATC situations compared to novices and intermediates.

Gaze data as a source for predicting driver intent via pattern recognition

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This study investigates the efficacy of gaze data as a source of information for predicting driver intent with respect to lane change manoeuvres. Gaze data, in combination with steering-wheel-angle data and vehicle velocity data, have been applied to Neural Network and Naïve Bayesian models in order to form models that infer the driver's intention from the data so that lane change events can be predicted. The effect of different combinations of the available data presented to the Neural Network and Naïve Bayesian models was investigated, i.e. gaze data with and without steering wheel data and / or vehicle velocity data. The results are presented, the limitations of the approaches used are discussed, and future approaches suggested.

Where do people look when using combined rating scales?

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We report on data obtained during an extensive video quality test. 27 Subjects were presented a series of degraded or undegraded videos on a HD screen and had to rate the quality subsequent to presentation on a scale recommended by the International Telecommunication Union (ITU-T Rec. P.910) resulting in 39 ratings per person. The scale consists of a vertical ruler-type continuous line with numeric labels from 0-10 on one side and verbal labels on the other side. As eye movements were recorded during the whole experiment (EYELINK 2, 250Hz binocular), it became evident that subjects almost never looked at the numeric labels (dwell time across all subjects 2.4%), but mostly on the verbal labels (dwell time 23.4%) and the line itself (dwell time 72.7%). Similarly, the first fixation in a rating trial was either on a verbal label (59% across all subjects) or on the line (37.1%), but rarely on a number (3.9%). Thus we conclude that the numbers in addition to verbal labels on a continuous scale are attended less for making the rating.

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Eye-Movement Software

EOGUI: A Matlab software to analyze electro-oculogram recordings

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We present a Matlab-based software to extract and parameterize blinks and saccades from the electro-oculogram (EOG). It takes raw data (vertical and horizontal channel separated) and returns single events in *.mat or ASCII format. The raw signal is filtered and events are detected using a velocity threshold. For each event parameters like duration, amplitude, maximum velocity and delay between closing and opening for blinks are available, taking into account known issues like signal overshoot or stepped saccades. A graphical user interface (GUI) enables the user to browse through the raw signal with the identified events marked in it. Dialogue boxes allow the user to visually specify noise, reference saccades or blinks, and signal changes during a prior calibration, i.e. saccades that correspond to a known change of visual angle. All settings are stored in a configuration file that can be used for the next data set. Supported input file types include Matlab and Brainvision files, and can be extended to other formats. Next to the GUI version also batch processing is possible. Both versions have been used for large data sets like in Schleicher et al. [2008, Ergonomics, 51(7), 982-1010]. The software will be available online at the time of the conference.

OpenSesame: A free, graphical experiment builder for the social sciences

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We introduce OpenSesame, a graphical experiment builder. OpenSesame is cross-platform and freely available under an open-source license. Compared with other software packages for creating experiments, OpenSesame distinguishes itself through a comprehensive and fully graphical user interface. Python, an intuitive and widely used programming language, is supported for complex tasks. Arbitrary functionality, such as support for external devices, can be added to OpenSesame by installing plug-ins. A plug-in that adds support for the EyeLink series of eye trackers (SR Research) is available, allowing experimenters to develop advanced (e.g., using fixation-triggered drift correction) and gaze-contingent paradigms, with minimal (if any) need for manual coding.

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Eye tracking in virtual 3D environments: Challenges and directions of future research

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Current stereoscopic visualization technologies allow for a realistic presentation of objects and scenes. Virtual reality environments are broadly employed in the entertainment industry and used for simulation. Moreover, the interest increases to understand how visual attention is distributed in simulated dynamic settings, e.g. for diverse medical applications [Burgert et al., 2007, Proc. SPIE 6515, 65150B]. For such studies, eye tracking provides the essential technology but is limited by the fact that the algorithms are optimized for 2D settings. The analysis of visual attention allocation in realistic virtual 3D environments requires combining visualization technologies and eye tracking. For a successful implementation of this approach, it is necessary to develop algorithms that allow for a reliable estimation of gaze positions in such environments. As a first step, we investigated possible influences of visualization techniques (shutter glasses and polarization filters) on the accuracy of recorded gaze data in different 2D and 3D environments. Based on the results, the depth information of 3D gaze positions was calculated. The validated results will be used as a basis for the development of new 3D fixation and saccade detection algorithms.

Frequent pattern mining on eye-tracking records decomposed into chunks

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Ordinary use of heat maps and scan paths on multiple eye-tracking records are subject to the influence of extreme cases just like the arithmetic mean tends to be pulled toward a few extreme values. Network analysis of the fixation sequences [Matsuda & Takeuchi, 2011a, *eMinds_2*(7), 3-16; Matsuda & Takeuchi, 2011b, *Journal of Eye Movement Research*, 4(1):5, 1-12] is not free from such influences. If one is interested in the common patterns across records, frequent pattern mining approach seems to be viable. To this end, we first decomposed the fixation sequences, obtained from web page viewers, into the sequences of chunks, using isolated saccades as delimiters. Just like shopping baskets, some chunks consisted of single fixations, while others contained multiple fixations. In the present work, the PrefixSpan algorithm [Pei et al., 2001, Proc of ICDE2001, 215-224] was applied to the chunk sequences and examined the changes of identified patterns by altering the threshold level called minimum support. Since the algorithm treats the multiple occurrence of an element within a chunk as one, we supplemented the analysis by an examination of such occurrence, particularly successive ones called loops.

A novel interpolation based method for the extraction of velocity profiles from low, medium and high frequency eye data

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This study presents a novel interpolation-based method for the extraction of velocity profiles, including peak velocities, from eye data with a minimum of 60Hz sampling frequency. Peak velocity is a clinically relevant diagnostic measure normally restricted to high temporal resolution eye tracking systems. We apply a univariate spline interpolation method and a calculus based error metric to low, mid and high frequency data measured at and decimated from 1250Hz SMI HiSpeed data. Results are presented according to the match of interpolated peak velocity at various levels of decimation to those read from high frequency data smoothed using the Savitzky-Golay FIR smoothing filter. The method is also tested against the peak velocities reported by the SR Research EyeLink II system, sampling at 500Hz. Data decimated to 62.5, 125, 250, and 625Hz all correlate with the original measured peaks; $r = .95$ to $.98$. This method represents a shift in thinking in terms of processing eye data for the detection of events, away from the frequency and into the spatial domain, arguing that the spatial domain offers superior possibilities for extraction of events from low frequency data and also that high frequency data can be enhanced and improved by incorporating such an approach.

Saccadic peak velocity as a mental state index in ecological tasks

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Applied research has identified the need to monitor human functional states in real-time to determine the level of automated assistance necessary during demanding tasks. The development of a psychophysiological marker which can measure on-line mental state would help identify diminished attentional and/or cognitive ability which is an important problem in society as the use of information technology grows. In this work, we present data from an ongoing research project about the validity and sensitivity of saccadic kinematics as mental state index in several everyday life domains. Six experiments, ranging from simulated air traffic control tasks to driving/riding simulator sessions, are graphically described. Our results demonstrate the validity and sensitivity of the saccadic peak velocity as a measure which can detect variations in mental workload/fatigue while doing complex and ecological tasks. According to these findings, the peak velocity analysis represents a valid on-line measure for the detection of changes in mental state, providing the basis for the development of new vigilance screening tools to prevent accidents in several applied domains. Furthermore, this research could provide several guidelines for designing adaptive systems with the ability to allocate tasks between operators and machines in a dynamic way.

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Eye-tracking for pupil diameter extraction

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In this study, an eye-tracker is used to follow eye movements. On each image the pupil and the iris are detected by using Hough transform. This transform usually used for straight line detection can also determine circles on images. The result of the Hough transform is an estimation of the circle features: the center position and the diameter. By using this transform, two concentric circles are detected on the images: one representing the iris boundary and the other one the pupil boundary. Then the ratio between pupil and iris diameters is computed in order to evaluate the pupil aperture. In this way, the eye behavior, and more precisely, changes of pupil aperture, can be easily studied. Several experiments have been made when using different stimuli. These different stimuli can be generated by lightning changes. The system gives the pupil diameter at each time of the experiment and curves can be drawn showing the pupil behavior.

An interactive software tool for eReading analysis

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"eReading" stands for the reading of eBooks, or any kind of electronic document, from computer displays, tablets, eReaders, etc. The most appropriate systems for recording eye movements during eReading are those based on videooculography. Usually, scanpath analysis results in fixations parameters, heatmaps, videogaze overlay and others. However, in order to study eye movement during reading, the horizontal component needs to be analyzed in much detail. An interactive approach has been implemented within the software developed for eReading analysis. First, the program can import different data formats, according to the recording device chosen for a specific experimental protocol. Second, pre-processing is needed in order to identify and extract from the entire experimental session the periods of recording during which the subject was reading and not exploring the scene. Reading sections analysis is fully automatic, although the operator has the possibility of modifying some default parameters such as threshold level for saccade identification and low-pass filtering cutoff, when needed. The program computes number of fixations, refixations, mean fixation duration, number of return sweeps and, most importantly, can chose to see vertical lines superimposed on the signal that indicate the identified saccades. The analysis report is saved in XLS format for further processing.

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Invited Talk

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To correct for eye movements, it is often suggested that the visual system uses efference copy from the oculomotor system. Here we consider the possibility that these correction signals arise from attention itself, as "covert efference copy". When an attended target moves on the retina, tracking processes must shift attention from the target's current to its next location. The vector of this upcoming displacement of attention is little different from, and available before, any oculomotor efference copy. The relevant vectors come only from shifts of attention that follow or predict movements of the same target; if instead attention switches from one target to another, this simply creates a new focus of attention and the displacement is not relevant for updating of any kind. A number of studies reveal when and how this covert efference copy can generate predictive shifts of attention, as well as providing the corresponding impression of object motion and coordinate transforms. For example, when a target is steady but the eyes are about to move, attention is directed not only to the saccade target but also "remapped" to its postsaccadic location even before the saccade happens [Rolfs, Jonikaitis, Deubel, & Cavanagh, 2011]. The correction vector required for this remapping is already present in the "covert efference copy" - the upcoming displacement of attention - and this signal can then be applied to other targets without calling on signals from the oculomotor system. Attention also moves predictively even when the eyes do not: Just as smooth pursuit can match a sinusoidally moving target with no lag, attention can track a moving target with no more than 25 ms error [Cavanagh, Holcombe & Chou, 2008], using the vector of its previous displacement to predict the next. These anticipatory functions of attention appear to be hosted in saccade control centers and are executed on a set of "attention pointers" [Cavanagh, Hunt, Afraz, & Rolfs, 2010]. These pointers provide the location code for their targets, conferring performance benefits and specifying saccade end points. The planned shifts of these pointers also provide signals, covert efference copy, that anticipate the effects of predictable eye and object motions.

Symposium - Extra-retinal signals for active vision

Perceptual consequences of presaccadic attention shifts

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When the eyes are about to move to a new location, attention is drawn there, resulting in a local increase in visual performance [e.g., Deubel & Schneider, 1996, *Vision Research*, 36, 1827-1837], which is remapped an instant before the eye movement to remain aligned with the changing target locations on the retina [Rolfs et al., 2011, *Nature Neuroscience*, 14, 252-256]. Tentative explanations of these effects rely on saccade preparation signals arising in eye movement control areas that feed back into visual cortex. To shed light on these mechanisms, we studied the visual consequences of presaccadic attention shifts on orientation discrimination performance and perceived contrast. In a series of experiments, we show that as time approaches the eye movement and performance in visual discrimination tasks improves at the saccade target, the perceived contrast of stimuli presented at that target location increases markedly. Both the increase in performance and in perceived contrast significantly exceed changes in a neutral (control) condition, in which observers did not saccade. These findings are compatible with a gain-control mechanism triggered by the preparation of saccadic eye movements that affects the incoming visual signal in a similar way as an increase in physical stimulus contrast.

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Presaccadic receptive field mappings in the frontal eye field

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The receptive fields (RFs) of neurons in many areas of the primate visual system are altered prior to the initiation of saccades. However, the exact nature of those RF dynamics is unknown. Typically, the changes of RFs have been inferred on the basis of few visual stimulus positions rather than from detailed spatial profiles. We measured detailed presaccadic RF profiles of frontal eye field (FEF) neurons by probing a large number (>72) of stimulus positions within a large portion of visual space. RF profiles were obtained both during passive fixation and immediately prior to the initiation of visually guided saccades. We recorded the responses of FEF neurons to probe stimuli ($1^\circ \times 1^\circ$ white squares) flashed (~ 20 ms) at random positions. On fixation trials, multiple positions were probed in succession at 0.5 Hz while the monkey maintained fixation. On each presaccadic trial, the monkey made a saccade to a visual target in the contralateral hemifield and a single position was probed within 100 ms of saccade initiation. Thus far, we find clear presaccadic changes in the RF profiles of FEF neurons. In particular, we observe that RFs move toward the saccade endpoint in a direction nonparallel to the saccade vector.

Frontal eye field neurons report whether visual stimuli stay stable, or move, during saccades

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Saccades aid vision but complicate it as well. A problem is that movements on the retina may be caused by saccades or actual movements in the scene. One way the brain may tell the difference is by monitoring corollary discharges of saccades. The frontal eye field (FEF) is a known recipient of corollary discharge, so we tested whether its neurons distinguish between visual stimuli that stay stable, or move, as saccades are made. We trained monkeys to make a saccade to a visual target in the presence of peripheral visual stimulus. The peripheral stimulus remained stable or moved during the saccade. We found that the responses of FEF neurons encoded whether the stimulus remained stable or not. Next we tested the link to perception. We trained monkeys to make scanning saccades between two visual targets. During one of the saccades, a peripheral visual stimulus moved to the center of the receptive field. A monkey's task was to report if the stimulus moved by immediately looking at it. We found that their FEF responses predicted their behavioral responses. Our results suggest that the FEF contributes to perceiving visual stimuli as they are in the world even as saccades are made.

Role of internal monitoring signals for space perception across saccades

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We continuously sample our visual environment by rapid sequences of saccadic eye movements. For the successful integration of visual information into a coherent scene representation, the visuo-motor system needs to distinguish these self-induced visual displacements from motion in the outside world. Internal forward models may help to solve this problem: The brain may use an internal monitoring signal associated with the oculomotor command to predict the visual consequences of the corresponding eye movement. Recent neurophysiological studies in primates identified one candidate monitoring pathway that ascends from the superior colliculus to the frontal cortex, relayed by medial thalamus. Data are presented from a case study in a patient with a lesion affecting trans-thalamic monitoring pathways and from healthy human subjects in which we disturbed the trans-saccadic integration of monitoring signals with transcranial magnetic stimulation (TMS) over a cortical target structure, the frontal eye fields (FEF). In both studies, we observed a lateralized impairment for the perceptual detection of intrasaccadic stimulus displacements. Our findings suggest an important role of internal monitoring signals in perceptual-motor integration across eye movements. Internal monitoring signals may be critical for the correct attribution of self-induced versus externally imposed changes in the continuous flow of our sensory experiences.

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The shape of visual remapping responses

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In order to maintain visual stability in the face of continuous saccadic eye movements, the brain has to incorporate the motor commands for upcoming saccades into visual processing. The process by which saccadic motor commands impinge on retinal processing is called remapping. In remapping, neurons with receptive fields sensitive to the post-saccadic retinotopic location of the stimulus preactivate before the saccade, and thus, before they receive visual input. Evidence for remapping responses has been found in areas ranging down to the lowest levels of visual cortex. We used phase-encoded signals in a functional imaging experiment. We investigated whether remapping responses at the fovea encode the shape of the saccade target, in this case a slowly rotating wedge presented in the periphery before repeated saccades. Information about the position of the wedge in its rotational trajectory can be found near the fovea, revealing the remapping response's shape. Our results indicate that remapping responses transfer position and shape information across the retinotopic maps involved in visual processing.

The role of efference copy in saccadic adaptation

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When saccades systematically miss their target, their amplitude adjusts and errors are progressively reduced. Conventionally, this adaptation is viewed as driven by retinal error (the distance between primary saccade endpoint and target). Implicitly, this view regards the variability in the saccade endpoint as noise. Recent work suggests that the oculomotor system is informed about where the eye lands; thus, not all "retinal error" is unexpected. The present study compared two error signals that may drive adaptation: retinal and prediction error (the difference between predicted and actual post-saccadic images). Participants made saccades to a target in two successive sessions. In the first, during saccade execution, the target was extinguished if the amplitude was smaller (or, in some experiments, greater) than the running median, thereby modifying the average retinal error without moving the target. In the second session, targets were extinguished at saccade onset and turned back on at a position that reproduced the trial-by-trial retinal error recorded on the first session. Adaptation proceeded approximately three times as rapidly during the second session, when the predicted target position had been changed, arguing that deviations from the predicted post-saccadic positions drive adaptation more strongly than retinal error alone.

Scenes III: Objects & Categories

Spatially accurate saccades to faces in complex scenes from 120ms

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Saccades to faces in a saccadic choice task start with latencies of only 100-110ms [Crouzet et al, 2010, *Journal of Vision*, 10(4):16, 1-17]. Here, we investigated the accuracy of these saccades using natural scenes containing a face target 1° in size. The images were cropped so that the face appeared in 16 different positions (eccentricities: 3.5° and 7°, 8 directions). The saccades were both fast and remarkably precise. The angular difference between the first saccade and the target was below 10° on over 60% of trials, and below 22.5% for over 90%. In term of distance, the average error was less than 2%. Median reaction time was a mere 153 ms, and performance was significantly above chance from 115 ms. Remarkably, the accuracy of the saccades before 150 ms was virtually as high as for later ones. Saccades to targets near the horizontal meridian were about 10 ms faster than for targets near the vertical axis. As a result, saccades made before 140 ms contained 50% more horizontal saccades than vertical ones, although accuracy was the same. These results show that the visual system is able to detect faces extremely rapidly and to initiate accurate saccades in just 120 ms.

Our eyes are captured by (the meaning of) faces

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Long-lasting debates question whether faces are special stimuli treated preferentially by our visual system or whether prioritized processing of faces is simply due to increased salience of their constituting features. To examine this issue, we used a visual search task in which participants had to make a saccade to the circle with a unique color among a set of six circles. Critically, there was a task-irrelevant object next to each circle. We examined how upright faces, inverted faces or a butterflies, presented near the target or non-target circles affected eye movements to the target. Upright (13.12%) and inverted faces (10.8%) located away from the target circle captured the eyes more than butterflies (8.5%), but upright faces captured the eyes more than inverted faces. Moreover, when faces were next to the target, upright faces, and to some extent inverted faces, facilitated the saccades towards the target. Faces are thus salient and capture attention. More importantly however above and beyond their raw salience based on low-level features, canonical upright faces capture attention stronger than inverted faces. Therefore, faces are 'special' and our visual system is tuned to their meaning and not only to low-level features making up a face.

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Entropy influence on spatial and category prediction

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Humans make anticipatory saccades to to-be-presented spatial locations when these are known in advance [e.g., Marcus et al., 2006; *Memory and Cognition*, 34, 420-432]. Using an eye-tracker, we examined whether people construct predictions for both the location and semantic category of a future item when such predictions are licensed, though uncertain. Experimental stimuli were 24 sequences, each consisting of 48 photos (presentation rate=1.6Hz). Photos appeared at one of four screen locations and were exemplars of four categories: faces, mammals, houses and cars. There were four experimental conditions in which location and category predictability were independently manipulated by constructing category and location sequences with high/low order as defined by the entropy of a 1st order Markov process. We found that highly predictable (though non-deterministic) locations prompted more anticipatory saccades than random sequences ($p = .014$) within 150ms prior to stimulus presentation, and within 150ms after stimulus presentation ($p < .001$). Furthermore, category predictability independently increased on-target fixations in this latter window ($p = .001$) indicating that being able to anticipate the semantic category of a future stimulus can facilitate fixation to its location.

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Guidance of search through scenes based on scene gist and non-foveal visual information

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Previewing scenes briefly makes finding target objects more efficient when viewing is through a gaze-contingent window (windowed viewing) [Castelhano & Henderson, 2007, *Journal of Experimental Psychology: Human Perception and Performance*, 33(4), 753-763]. Here we test whether gist extracted from the preview has the same effect when the scene is fully visible. A 250ms preview of the scene was sometimes presented before learning what the target object would be. While searching, participants were subject to windowed viewing or full-scene viewing. For windowed viewing, there was a clear preview advantage in terms of decreased response time, number of fixations, increased saccade amplitude, and distance of fixations from the target. For full-scene viewing, previewing the scene benefitted fixation duration and saccade amplitudes, but for trials in which the target was not found within six fixations, the first six fixations were not closer to the target after a preview. For trials requiring six or fewer fixations, fixations were closer to the target for about three fixations. The gist information derived from the initial glimpse of a scene can be used to plan eye movements, but when non-foveal information is available, initial scene gist only influences the first few fixations.

Basic and subordinate level categorizations of real-world scenes

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Previous research has tended to study the diagnostic information that facilitates scene categorization at a particular level of detail (e.g., a basic level: a classroom, a restaurant, etc.). However, scenes can be categorized at different levels of specificity (e.g., a classroom could more specifically be categorized as a lecture theatre). Here, we examined whether diagnostic information for scene categorization differed in nature and location as a function of the level of specificity. Participants were presented grey-scale scenes in four basic-level categories, with each category having exemplars from a further four subcategories. Participants categorized each scene either at a basic (e.g., classroom) or subordinate (e.g., lecture theatre) level in a 4AFC task. Critically, participants viewed scenes through a gaze-contingent window that presented full-resolution information to the fovea and low-passed information in the periphery. Participants therefore always had access to a scene's coarse, spatial-layout, while finer, local details were only available through fixation. Analyzed behavior and fixation data showed that in most of the scene categories, the distribution of fixations differed significantly between basic and subordinate tasks. The results therefore suggest that the diagnostic information required for scene categorization changes in nature and location as a function of task specificity.

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Words and pictures: The effects of semantic congruence on overt visual attention

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Novelty, or surprise, is commonly regarded as an important contributor to aesthetic preference. Aesthetically pleasing stimuli have been shown to attract and maintain our visual attention, and it has been suggested that unexpected or incongruous objects within a scene have a similar effect. We used the gaze driven evolutionary algorithm, which employs an oculomotor signature associated with aesthetic preference [Holmes & Zanker, 2009, *ECEM*; Zanker, Voigt & Holmes, 2010, *Journal of Vision*, 10(7):162] to explore the role of congruity in the evaluation of package designs for savoury snacks. Designs could vary independently in terms of colour and the choice and composition of images on the label. 24 participants were presented with package designs sampled from two identically generated starting populations whose only difference was the flavour name. Under free-viewing conditions, designs for the two flavours diverged significantly ($p < 0.001$) for each participant, suggesting a strong effect from the flavour name. Consistency between the participants' designs seemed to be dependent on the strength of association between the flavour names and the images on the final labels. The results indicate an exciting potential to use the methodology in the real-time exploration of bottom-up and top-down effects on preferential looking with complex stimuli.

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Reading II: Orthography & Morphology

Inhibitory orthographic neighbourhood effects during reading in Chinese

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In alphabetic languages, a word's orthographic neighbors influence its lexical identification in unmasked and masked priming [Segui & Grainger, 1990, *Journal of Experimental Psychology: Human Perception and Performance*, 16(1), 65-76; Davis & Lupker, 2006, *Journal of Experimental Psychology: Human Perception and Performance*, 32(3), 668-687], as well as during normal reading [Paterson et al., 2009, *Psychonomic Bulletin & Review*, 16(1), 43-50; Paterson et al., 2010, *Language and Cognitive Processes*, 26, 600-623]. We investigated whether a Chinese character that was an orthographic neighbor of a target character similarly influenced target character identification. Prime and target characters differed by one or two strokes, and their relative frequency was also manipulated. We conducted two forward masked lexical priming studies (60ms and 35ms primes), and an eye movement study in which the prime word preceded the target word in the sentence. Robust frequency effects were obtained in all three experiments. We also consistently obtained reliable inhibitory priming effects between prime and target characters regardless of target frequency. These findings replicate Paterson et al. (2009; 2010) for Chinese characters. The eye movement data demonstrate that robust orthographic neighborhood priming effects (stroke overlap) occur at the level of the character in Chinese reading.

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Phonological and orthographic overlap effects in fast priming

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We used the fast priming paradigm to examine the influence of phonological and orthographic overlap between prime and target. We tested 4 types of overlap: (1) high-phonological high-orthographic end-overlap (P+O+: track-crack), (2) P+O+ begin-overlap (swoop-swoon), (3) low-phonological high-orthographic overlap (P-O+: bear-gear), and (4), high-phonological low-orthographic overlap (P+O-: fruit-chute). The primes were always higher in frequency than the target and were presented for either 32 or 50 ms, before being replaced by the target word. Single fixation and gaze duration analyses showed facilitatory priming for both P+O+ conditions, which did not differ from each other, at both prime durations. The single fixation duration analyses indicated that the priming effect was greater, and that the target word was read faster, when both phonology and orthography overlapped than when the overlap was only at the phonological or the orthographic level. Finally, for P+O- items, no priming was observed at the shortest prime duration. These results point to a substantially greater reliance on orthographic information during reading and indicates that conflicting phonological information can easily be ignored. At the same time, consistent phonological information can slightly boost recognition. We will discuss these results in light of recent models of word recognition.

Eye fixation patterns on novel and existing compound words during reading

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Adult participants read sentences in which novel (maanantaikriisi = Monday crisis) and existing (tutkimusosasto = research department) two-constituent Finnish compound words appeared while their eye movements were measured. The frequency of the first constituent of the compounds was also varied factorially and the frequency of the existing compound words was equated over the two conditions. The sentence frames prior to the target word were matched across conditions. Both lexicality and first constituent frequency had large and significant effects on gaze durations on the target word. Moreover, the constituent frequency effect was significantly larger for the novel words. These results indicate that first constituent frequency has an effect in two stages: in the initial encoding of the compound word and in the construction of meaning for the novel compound word. The difference between this pattern of results and those for English prefixed words [Pollatsek et al., 2008, *Language and Cognitive Processes*, 23, 1133-1158] is apparently due to differences in the construction of meaning stage. A general model of the relationship of the processing of polymorphemic words to how they are fixated is presented.

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Access to embedded words in reading in the absence of morphological/semantic relationships

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Past eye movement studies have demonstrated that readers decompose morphologically complex words into their constituent morphemes during reading and that high frequency morphemes typically speed processing [e.g. Juhasz et al., 2003, *British Journal of Psychology*, 94, 223-244; Niswander et al., 2000, *Language and Cognitive Processes*, 15, 389-420]. The present experiments examined whether components within words are accessed in the absence of morphological/semantic relationships. In the first experiment, monomorphemic words with high frequency embedded words (e.g. barn) or low frequency embedded words (e.g. bunk) were read in matched sentence frames. High frequency embedded words produced significant disruption in gaze durations on the target word, suggesting they were accessed during fixation and interfered with target word identification. In a second experiment, apparent suffixed words with no morphological/semantic relationship were compared with truly suffixed words (e.g. early compared with gloomy: selected from Rastle et al. [2004, *Psychonomic Bulletin & Review*, 11, 1090-1098]). Fixation durations did not differ for these two types of words. Combined, both experiments suggest that access to embedded words in text occurs during the course of normal reading even in the absence of a morphological/semantic relationship. Implications for theories of eye movements in reading and morphological processing will be discussed.

Sensitivity to morphological information in the parafovea: Its implications for lexical access during reading

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We will report two experiments that investigated whether the morphology of the upcoming noun could be extracted parafoveally during reading English sentences. In the first experiment we will investigate the fixation probabilities and durations on nouns (book/books) when there is an initial mismatch between the article (these/the) and the subsequent noun. If readers are more likely to access morphological information from the parafovea when this information is predicted, this should reflect itself in skipping rates and following fixation durations on the parafoveal word. The second experiment will investigate processing of typical form features of the parafoveal noun, when there is a strong expectation for a noun then when there is not; in an eye tracking experiment. In a MEG study Rabagliati et al. [2010, *Psychological Science*, 21(5), 629-634] showed that when a noun is predicted the typical form features that are associated with that category is also activated. We will manipulate the availability of the parafoveal preview information. If there is sensitivity to typical features of the predicted syntactic category this should also influence the processing of the morphological information in the parafovea. We will discuss the implications of these results for models of lexical access in sentence processing and for the reading models.

Reading in Chinese, English and Finnish: A cross linguistic eye movement investigation

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Written Chinese, English and Finnish differ in many respects (ideographic vs. alphabetic text, word spacing, morphology, etc.). To investigate differences in reading between these three different languages, we recorded eye movements when participants read texts in their native language. The texts were carefully translated from English to Chinese and Finnish by competent bilingual speakers to ensure consistency across languages. Twenty-five Chinese, 21 English and 20 Finnish college students participated in the experiment. Paragraph-level analyses were conducted to examine general reading differences across the languages. LME analyses were conducted to examine the relative contribution of linguistic variables to performance differences, along with local analyses of (morphologically) complex target words. Briefly, overall reading speed (words per minute) was faster in English than in Chinese and Finnish, mean fixation durations were longest for Chinese and shortest for Finnish and average saccade length was shortest for Chinese, longer for English, and longest for Finnish. These effects are due to differences in the spatial and linguistic density of the languages. Interestingly, despite substantive differences in eye movements between languages, the total time to understand the texts did not differ. Thus, whilst language-specific characteristics produced variability in oculomotor dynamics, we observed universality in attainment of comprehension.

Visual Fixation

Modulations of small fixational eye movements by low-level factors in a visual object classification task

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Recent studies indicate that small fixational eye movements can be modulated by high-level factors [Ottero-Millan et al., 2008, *Journal of Vision*, 8 (14), 1-18; Yuval-Greenberg et al., 2008, *Neuron*, 58 (3), 429-441], which suggests that they might be modulated by higher cognitive processes. The following study attempted to assess the scope of high-level and low-level modulations of these movements. Both types of modulations were introduced simultaneously in a task requiring the participants to decide whether the presented line-drawing represented a nameable, familiar object or a novel, unfamiliar object. Drawings were defined along different directions in cardinal colour space: 1) S-cone-isolating (S), 2) intermediate-isoluminant (S and L-M cone), 3) a full-colour stimulus, containing an additional achromatic component (S; L-M; L+M+S cone). Small fixational saccade rates measured at 200-400 milliseconds after stimulus onset were shown to be modulated by low-level factors, with least fixational eye movements for S-cone isolating stimuli as opposed to full-colour stimuli. There was no significant effect of object class. The lack of involvement of S cones in foveal processing might explain the lowest fixational saccade rates for S-cone isolating stimuli. The study demonstrated that fixational movements were predominantly driven by low-level factors, such as colour and luminance information.

Microsaccadic amplitude and rate are modulated differentially by spatial frequency and subjective visibility

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Microsaccades (MS) are ballistic fixational eye movements that prevent fading during fixation. It has been reported that MS parameters correlate with visibility of a stimulus, and with the stimulus parameters, e.g. spatial frequency (SF). However, it is unknown whether the visibility effect depends on the stimulus properties, like SF. Such a dependency would indicate that the oculomotor system programs MS to extract specific information. Here, we address this question using the Troxler paradigm. We present peripheral stimuli at SFs of 0.3, 1.5, and 4 cpd and ask the subject to report their visibility by button press. We find no interaction between visibility and SF either for MS amplitude or rate. However, MS rate increased before stimuli became visible and decreased when stimuli faded. MS amplitude differed between SFs before any perceptual switch, with larger MS amplitudes for lower SFs. Taken together, our results confirm the relevance of MS rate for subjective visibility of peripheral stimuli and provide evidence that the modulation of MS amplitude by SF is a complementary feature, independent of the stimuli's subjective visibility.

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The effect of drift and microsaccades on the dependence between fixational eye movement

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Even while fixating a stationary object, our eyes perform miniature (or fixational) movements involuntarily. These movements are the superposition of three types of motion: small amplitude tremor, slow drift and rapid microsaccades. Although there is a common general agreement that microsaccades might have a central generating mechanism, the origin of drift is unclear and matter of controversial findings. A direct way to investigate whether drift is the result of independent oculomotor noise is to quantify its influence on the dependence between the components, within and across the eyes, of fixational eye movements (FEM). In this work we investigate the statistical dependence between the horizontal and vertical velocity of FEM, within and across the eyes. To discriminate possible different contributions of drift and microsaccades, we removed the microsaccades from the time series and we compared the resulting dependencies. Our analysis shows that the large dependence measured between parallel (across the eyes) components of the velocity is mostly due to the drift. This result is inconsistent with a drift resulting from noisy firing of peripheral neurons. Our results are compatible with the assumption of a common mechanism that modulates not only microsaccades, but also drift, and FEM in general.

Eye accommodation behaviour in response to sizes of visual stimuli

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To estimate the size of an object, viewers' eye movements were analyzed while the eyes accommodated themselves in the time between stimulus onset and response after recognizing the stimulus, which was the gap in a Landolt circle. Six stimulus sizes (visual angles: 0.32, 0.64, 0.96, 1.28, 2.23, 3.19 degrees) were shown to 6 participants using a PC-LCD monitor under two experimental conditions. The fixation size as a magnitude of eye movements was evaluated in the first and the second 500 ms after stimulus onset since the mean reaction time was approximately 500 ms after viewers were asked about the gap. There is no significant difference in the fixation size of eye movements between the two experimental conditions. Stimuli size is a significant factor for means of fixation sizes of 500-1000 ms ($F(5,25)=5.0$, $p<0.01$), while means for 0-500 ms are almost always constant across 6 stimuli sizes and are much smaller than the means for 500-1000 ms. The deviations of fixation sizes for 0-500 ms are larger than those for 500-1000 ms, and increase as the stimulus sizes become larger. These results provide evidence that eye movements reflect the size of objects viewed.

Main contributor of this work is MF.

Micro-OKN may explain perceptual anisotropies observed for ambiguous plaids moving in oblique and cardinal directions

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Moving plaids are ambiguous stimuli that can be perceived either as a coherent pattern moving rigidly or as two gratings sliding over each other. Prolonged observation leads to bistable alternation between coherency and transparency [Hupé & Rubin, 2003, *Vision Research*, 43, 531-548]. Plaids moving in oblique directions are perceived as sliding more frequently than plaids moving in cardinal directions, and plaids moving in horizontal directions cohere more than plaids moving in vertical directions ('oblique plaid effect': [Hupé & Rubin, 2004, *Vision Research*, 44, 489-500]). I tested whether eye movements could explain these anisotropies. Even under steady fixation moving plaids generate small optokinetic nystagmus (OKN) along the directions of both component (1D) and pattern (2D) motion. Micro-OKN were more frequent along horizontal directions whatever the plaid direction and perceptual report. As a result, the relative proportion of OKN along 1D and 2D directions was modulated by the plaid direction in a way consistent with perceptual anisotropies. Moreover, the amplitude of this modulation in individual subjects was correlated with the strength of the oblique plaid effect, suggesting an influence of micro-OKN on perceptual decisions, in line with the results of [Laubrock et al., 2008, *Journal of Vision*, 8(14), 13.1-17].

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Microsaccades and exploratory saccades in a driving environment

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Microsaccades, small saccadic eye movements made during fixation, might accompany shifts of visual attention, serve to refresh the retinal image, or have some other function. The relative importance of these functions was tested in a simulated driving environment by recording exploratory saccades and microsaccades with a head mounted eye tracker. Participants performed a lane-change task, accompanied by a simultaneous visual search task in which drivers searched for a target among similar distractors on a panel to the driver's right where an electronic display would normally be located. After training, observers performed a baseline run with the lane-change task only, followed by four dual-task runs and a final control run. In the dual-task condition, where more visual attention shifts occur, we found a significantly increased frequency of microsaccades along with an even larger increase in frequency of large exploratory saccades. However the proportion of microsaccades significantly decreased in the dual task, consistent with the idea of a common neurological origin for microsaccades and exploratory saccades

Symposium - The influence of visual distracters on eye movements

The impact of visual distracters on saccade latency

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Saccade latency has been shown to increase as the ratio of the distance of the distracter and the target from fixation decreases. In conflicting results latency has been shown to increase even when this ratio is kept constant. These latter studies involved an element of target selection not present in the former. To examine this, we minimised target selection processes. We recorded saccade latencies to two lateralized targets on the horizontal meridian while distracters were shown at three eccentricities on three different axes. We found that a distracter at the closest eccentricity slowed the saccade by ~15ms relative to the other two (which produced no significant slowing and were equivalent) across all three distracter axes. Thus when target selection processes are minimised it is the distracter-target ratio that impacts on saccade latency. Unexpectedly, there was also found to be an overall slowing of saccade latencies across all three distracter eccentricities when they were shown on the axis diametrically opposite the target. Further experiments suggest that this may be due to an increase in the activation at locations in the same direction as the "return to fixation" saccade leading to a greater interference of these in fixation disengagement.

Modulation of saccadic inhibition by distractor size depends on distractor location

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Saccade execution is inhibited by visual transients presented during a labile period of saccade preparation. This saccadic inhibition typically reaches its maximum at about 90 ms after the transient, with a subsequent recovery period. We studied how the size and the field of presentation of the distractor influence parameters of saccadic inhibition. We first demonstrated that the size of a distractor presented in the contralateral visual field does not influence the timing of saccadic inhibition but has a logarithmic relationship with inhibition magnitude. This implies that the probability of SI occurring, for a given saccade, increases logarithmically with the size of a contralateral distractor. We then compared the effect of size for distractors in the contralateral or in the ipsilateral hemifield to the target. Larger distractors in either field produced stronger inhibition, but this increase was much more pronounced in the ipsilateral field. We hypothesise that saccadic inhibition in the ipsilateral field may result in a stronger inhibition since attention preallocated at target location magnified distractor influence. The results are also discussed in relation to the superior colliculus map organisation.

Saccadic inhibition, exogenous signals and eye movement models

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Visual onsets appearing while an observer plans a saccade knock out a sub- population of saccadic latencies that would otherwise occur, creating a dip in the saccade distribution - a phenomenon referred to as "saccadic inhibition". The dip is remarkably well time-locked across conditions and observers, clearly revealing and characterising a fast automatic component of visual input to oculomotor competition. Here we find that the 'saccadic inhibition' effect: 1) is not accounted for by current single process decision models, even after significant additions, 2) can be explained by existing complex (neuronal field) models, and 3) constrains crucial temporal parameters of the model, precisely enough to address individual differences. The neural field model also predicts further features borne out by our data: the dips show spatial specificity, are lawfully modulated by contrast, and occur with S-cone stimuli invisible to the retinotectal route. Overall, our data provide a way forward for overcoming one of the main impediments in moving from elegant models to more complex biological models in humans - the ability to constrain the more numerous parameters with behavioural data.

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Time-course of feature-based top-down control in saccadic distractor effects

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In a search task, participants made a saccade towards a target stimulus of a predefined feature. On some trials, a distractor stimulus was presented that either shared the target feature or was dissimilar to the target. Saccadic reaction times (SRTs) were more strongly slowed by distractors that were similar to the target than by dissimilar distractors (similarity effect). The time course of the similarity effect was investigated by varying target contrast and analyzing SRT distributions. When the distractor was in the fovea, the similarity effect increased with increasing SRTs, suggesting that top-down enhancement of task-relevant features increased over time. The growing enhancement allowed for successful saccades to the peripheral target location, but also entailed larger distraction by stimuli sharing the enhanced feature. In contrast, similarity effects with peripheral distractors did not grow stronger with increasing SRTs, which we attribute to location-based inhibition. Strong inhibition was likely with peripheral distractors because they always appeared at the same task-irrelevant location. Prior inhibition with foveal distractors was weaker because this would have partially released fixation and entailed anticipations. In sum, enhancement of target-similar features was not eliminated by location-based inhibition, but its increase was contained.

On the limits of top-down control in saccadic selection

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Observers were instructed to make a speeded saccade to one of two color singletons. Before each trial, observers received a word cue (e.g., 'red', or 'green') telling them which color singleton was the saccade target. Even though most theories of search predict that observers should be perfectly able to select the singleton relevant for the task at hand, the present study shows that observers often made a saccade to the distractor singleton. Importantly, only when the color of the target singleton remained the same from one trial to the next, observers were perfectly able to make a saccade to the correct singleton, an effect that we consider to be the result of passive automatic intertrial priming. The present study demonstrates that top-down control over saccadic eye movements is limited. The eyes tend to go to the object that was the target on the previous trial, even if observers are instructed to look for something else. It shows that saccadic selection is basically the result of automatic and passive processing.

The influence of random-dot noise on smooth pursuit and perception

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We investigated how the visual system and the pursuit system react to motion noise. We presented three different types of random-dot kinematograms at five different coherences. For transparent motion, the signal and noise labels on each dot were preserved throughout each trial, and noise dots moved with the same speed as the signal dots but in fixed random directions. For white noise motion, every 20 ms the signal and noise labels were randomly assigned to each dot and noise dots appeared at random positions. For Brownian motion, signal and noise labels were also randomly assigned, but the noise dots moved at the signal speed in a direction that varied randomly. Neither pursuit latency nor early eye acceleration differed among the different types of kinematograms. Late acceleration, pursuit gain, and perceived speed all depended on kinematogram type, with good agreement between pursuit gain and perceived speed. For transparent motion, pursuit gain and perceived speed were independent of coherence. For white and Brownian motions, pursuit gain and perceived speed increased with coherence but were higher for white than for Brownian motion. This suggests that under our conditions, the pursuit system integrates across all directions of motion but not across all speeds.

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Reading III: Parafoveal Preview

Direct lexical control of eye movements in reading: Evidence from survival analyses of fixation durations

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Participants' eye movements were monitored in an experiment that manipulated the word frequency of target words (high vs. low) as well as the availability of the target words for parafoveal processing during fixations on the pre-target word (valid vs. invalid preview). The influence of the word-frequency by preview-validity manipulation on the distributions of first-fixation duration was examined by using *ex-Gaussian* fitting as well as by introducing a novel survival analysis technique which provided precise estimates of the timing of the first discernible influence of word frequency on first-fixation duration. Using this technique, we found a significant influence of word frequency on fixation duration in normal reading (valid preview) as early as 144 ms from the start of fixation. In contrast, the influence of word frequency occurred as early as 255 ms in the invalid preview condition. The present findings provide strong support for the crucial role of parafoveal processing in enabling direct lexical control of reading fixation times. Implications for models of eye-movement control are discussed.

Preview benefit vs masked priming

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There is a fine tradition in eye movement research using the 'boundary technique' [Rayner, 1975, *Cognitive Psychology*, 7, 65-81] to examine the nature of parafoveal preview benefit. A similar tradition exists within the word recognition literature involving the 'masked priming' technique [Forster & Davis, 1984, *Journal of Experimental Psychology*, 10, 680-698] to examine aspects of lexical access. However, while there has been some (usually informal) speculation regarding similarities and differences in the mechanisms engaged, there has not previously been a direct comparison of the findings from both techniques. The studies reported here used both the boundary technique and masked priming to examine the nature of the 'tuning' of lexical representations. The studies orthogonally manipulated word frequency and neighbourhood size and the nature of the 'prime' stimulus, across 5 conditions. At a theoretical level, the results from both studies suggest that neighbourhood density does not exert the sort of effect anticipated in most recent models of the process of word recognition. At a methodological level, the results show many of the anticipated similarities across techniques, but also reveal important early differences that provide an important insight into the nature of the processes engaged by both techniques.

Explorations of the word-predictability effect: Is it really predictability?

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We address the question of whether the effect of word-predictability on eye movements reflects a facilitation of lexical access or whether it might be driven by later processes, such as semantic integration. In Experiment 1, eye-movements were recorded while participants read sentences which varied across four levels of predictability towards a particular target word (e.g. 'ducks'). The results showed an inverse monotonic relationship between level of sentential constraint and target word inspection time; an outcome consistent with either of the aforementioned accounts. In Experiment 2, the same set of experimental sentences were employed, but with the target word replaced by a non-predictable but semantically appropriate and plausible word (e.g. 'geese'). Using an eye-movement contingent procedure, the target-preview was also manipulated so that it was either the predictable word (e.g. 'ducks') or non-predictable (e.g. 'geese'). There was no interaction with preview, and the pattern of inspection times on the target word matched that found with predictable targets. Since this target-word was always unpredictable, the effect seems more likely to be related to semantic integration than to lexical facilitation. This outcome is incompatible with models of eye-movement control which assume that predictability primarily influences the speed of lexical access.

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Semantic preview benefit during reading and the influence of German noun capitalization

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Word features in parafoveal vision influence eye movements in reading. The question whether readers extract semantic information from parafoveal words was studied with two experiments employing a gaze-contingent display change technique. Subjects read German sentences containing a critical target word for which a parafoveal preview was presented. The target replaced the preview word during the saccade to the parafoveal preview that was either semantically related or unrelated to the target. To facilitate parafoveal processing, a high-frequency word directly preceded the target. Fixation durations on the target word were shorter when a semantically related parafoveal word was presented. All experimental previews and targets were nouns. There is a unique characteristic of German script: the capitalizations of all nouns, i.e., nouns are printed with an initial capital letter and hence may alleviate parafoveal processing. In the second experiment, one half of the sentences was presented following the German rules and one half was presented completely in lower-case. Results indicate semantic preview benefit was obtained under both conditions.

Chinese compound character parafoveal decomposition and semantic information extraction

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Semantic preview benefit is elusive in English, and it has only been demonstrated for a restricted set of simple and frequent Chinese characters. Using the gaze contingent boundary paradigm, this experiment examined whether parafoveal semantic information could also be extracted from compound preview characters, which were more representative for the Chinese writing system. More importantly, we also manipulated the radical semantic transparency (i.e., the degree to which the constituent radicals are semantically related to meaning of the whole character) of the preview characters. Results generalized parafoveal semantic processing to this representative set of Chinese characters and extended the parafoveal processing to radical (sub-lexical) level semantic information extraction. In addition, the semantic preview benefit was modulated by preview duration (i.e., the amount of time the eyes spent on the preboundary word). Implications for notions of time course of parafoveal information extraction during Chinese reading are discussed.

Emotional facilitation vs. inhibition during reading reflects attention capture before vs. after target word fixation

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People can experience powerful emotional reactions while reading. Prior work shows that lexical decisions are faster for emotionally positive and negative words, relative to neutral ones [Kousta et al., 2009, *Cognition*, 112(3), 473-481], and that word emotionality is distinguished in the ERP record as early as the P1 component [Scott et al., 2009, *Biological Psychology*, 80(1), 95-104]. These effects suggest that emotionality modulates attention, consistent with work showing emotion effects on perception and cognition generally. We hypothesized that emotion words, relative to neutral ones, are prioritized by attentional mechanisms during natural reading. A total of 252 target words were presented to 40 native English participants within sentential contexts. Fixation durations on the target word and the word preceding the target were analyzed using linear mixed-effects regression. The analyses revealed that high frequency emotional words are read more quickly because they are processed parafoveally, prior to being fixated. Low frequency emotional words, however, are read more slowly because they do not capture attention parafoveally, and are processed only when directly fixated. The results are discussed in terms of cascaded word recognition systems that provide fast access to semantics and top-down signals that bias the processing of emotionally significant stimuli.

Transsaccadic Integration

Suppressing saccadic suppression

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The displacement of a target during saccades is very difficult to detect compared to the same displacement during fixation, a phenomenon called saccadic suppression of displacement. Displacements parallel to the saccade are harder to detect than perpendicular ones. Here we report a surprising interaction. Subjects made horizontal saccades and reported the direction, left or right, of any horizontal displacement. Thresholds for displacements made during the saccade were, as expected, quite high, but adding a task-irrelevant vertical offset lowered thresholds for the horizontal displacement by a factor of two or three. The same horizontal displacement that was undetected when presented alone was accurately reported when coupled to a vertical displacement. These results are a spatial equivalent of the temporal gap effect of Deubel et al. [1996, *Vision Research*, 36(7), 985-996] and suggest that, following a saccade, there is a spatial window elongated along the saccade direction, in addition to the temporal window of Deubel et al.. If the target is discovered within that spatiotemporal zone, spatial coordinates are calibrated to its new location and no displacement is seen. If a suitable target is not present in this region, trans-saccadic apparent motion is perceived in head-centric coordinates, revealing the accuracy of remapping.

Detection of target displacement across saccades in cortical blindness

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Keeping track of the spatial location of objects across saccades requires updating their retinal coordinates according to the vector of the eye movement. We examined the maintenance of location information in a patient with a lesion including V1 and the thalamus. The patient has no apparent residual visual capacity in the upper left visual quadrant. On each trial he made two saccades, which shifted a visual target into the blind quadrant and then out again. The target was removed during the first saccade and reappeared during the second saccade. On half the trials the stimulus was displaced from its original position. Random variation in the location of the fixations was introduced to prevent encoding of target location based on landmarks. In the control condition the two saccades shifted the stimulus within the sighted field. Detection of the displacement was above chance in both conditions, but performance in the sighted field was significantly higher than in the blind field. These results show that when a saccade shifts the remembered position of a stimulus location into the blind field, the representation is degraded, suggesting intact V1 and thalamus play critical roles in maintaining spatial representations across eye movements.

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Context dependence of receptive field remapping in the superior colliculus of macaque monkey

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Our perception of the positions of objects is surprisingly unaffected by saccadic eye movements. This suggests the brain maintains perceptual stability based either on the spatial relationships among visible objects or internal copies of its own motor commands. Strong evidence for the latter mechanism comes from the remapping of visual receptive fields that occurs around the time of saccades. Remapping occurs when a neuron responds pre-saccadically to a visual probe placed at the spatial location the cell's receptive field will occupy after the saccade. Although evidence for remapping has been found in many brain areas, relatively little is known about how remapping is affected by other visual objects in the background. Here we studied remapping responses of single neurons in the macaque monkey superior colliculus during different visual stimulus conditions: visual probe on a completely dark background (classic paradigm); probe presented on a dimly lit background (~ 0.03 cd/m²); dark probe on a white background; sparse noise mapping (reverse correlation). Remapping responses, though common in complete darkness, were significantly decreased ($p < 0.001$) during modest background illumination, inverted stimuli ($p < 0.001$), or reverse correlation. Thus the brain might use a strategy that emphasizes visual landmarks over extraretinal signals whenever the former are available.

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Optimal and suboptimal use of post-saccadic vision in sequences of saccades

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Saccades are imprecise, due to sensory and motor noise. To avoid an accumulation of errors during sequences of saccades, an efference copy-based prediction can be combined with the reafferent visual feedback to adjust the following eye movement. By varying the information quantity of the visual feedback, we investigated how the reliability of the visual information affects the post-saccadic update. Two elements of the visual scene were manipulated, the saccade target or the background, presented either together or in isolation. We determined the weight of the post-saccadic visual information by measuring the effect of intra-saccadic visual shifts on the following saccade. We confirmed that the weight of visual information evolves with information quantity as predicted for a statistically optimal system. In particular, we found that information from target and background are optimally combined. Moreover, these visual weights are adjusted dynamically to the level of visual noise determined by target eccentricity and reaction time. In contrast, we uncovered a dissociation between the visual signals used to update the next planned saccade and those used to generate an involuntary corrective saccade. The latter was exclusively based on target visual information, and discarded all information about the background: a suboptimal use of visual evidence.

Direct control vs. preprogramming of refixation saccades in reading: Saccade amplitudes can be misleading

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Within-word refixation saccades are generally assumed to result from sub-optimal initial landing positions and/or lexical processing difficulties. This direct control view has been challenged by Beauvillain et al., who suggested that when a word is refixated, the within-word saccade is planned as one package together with the initial inter-word saccade [e.g., Vergilino-Perez & Beauvillain, 2004, *Psychonomic Bulletin & Review*, 11(2), 332-337]. The present sentence reading study employed saccade contingent display manipulations to either shift a target word while the rest of the line remained stationary or to shift the whole line with the exception of the target word. In this paradigm, a pre-programmed refixation saccade should not change as a result of the mismatch between pre- and post-shift visual configurations. Indeed, there was little change in saccade amplitude (as found by Beauvillain and colleagues), but frequency, direction and landing position of refixation saccades were contingent upon the initial fixation position within the new word location. We suggest that refixation saccades are indeed primarily programmed on the basis of information from the current fixation, and amplitudes alone may provide a misleading account of saccade programming. Local oculomotor control parameters need to be seen in conjunction, as demonstrated by the changes in proportions between progressive and regressive refixation saccades.

The eyes are driven by visual mechanisms that receive novel inputs across saccades

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In richly textured visual environments, visual mechanisms will receive different inputs in quick succession as the eyes move around. In short sequences of saccades we examined how this history of trans-saccadic visual stimulation influenced subsequent eye movement decisions. During an initial saccade to the centre of the screen, a test display appeared with two noisy luminance patterns. Participants had to direct their second saccade to the higher contrast pattern. In Experiment 1 the display was blank during the first fixation and visual mechanisms received novel inputs after the initial saccade. Observers had a strong preference for patterns located in approximately the same movement direction (saccadic momentum). In Experiment 2 there were four equal contrast preview patterns arranged such that a visual mechanism may receive the same (retinotopically similar) or a novel (retinotopic onset) input after the saccade. All observers preferred retinotopic onsets, overturning the basic momentum effect. In Experiment 3 observers judged the luminance of a single, post-saccadic test pattern relative to the preview patterns. The apparent luminance of retinotopic onsets was enhanced, suggesting they trigger a larger internal sensory response that attracts the eye. Such a bias could direct the eyes towards discontinuities in a spatiotopically stable scene.

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Symposium - Biomimetic eye movements

The fine structure of bee and wasp head movements during visual homing

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Bees and wasps turn their thorax and thus their flight motor to change direction or to fly sideways. If the bee's head were fixed to its thorax such movements would have great impact on vision. Head movements independent of thorax orientation stabilise gaze and thus play an important and active role in shaping the structure of the visual input the animal receives. Here we investigate how gaze and flight control interact in homing tasks. We use high-speed video equipment to record the head- and body-movements of bees and wasps approaching and departing from a goal location. During these flights the trajectories consist of straight flight segments combined with rapid turns. These short and fast yaw turns ("saccades") are in most cases accompanied by even faster head yaw turns that start earlier than the body movements. Between saccades gaze stabilization leads to a behavioural elimination of rotational components from the optical flow pattern, which facilitates depth perception from motion parallax.

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A bio-inspired robot accounts for insect behavior

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Based on a biorobotic approach developed in our laboratory over the past 25 years, we have built several terrestrial and aerial vehicles controlled on the basis of Optic Flow (OF) cues [Rev. Franceschini, 2009, *Acta Futura*, 3, 15-34]. The LORA III robot is a miniature hovercraft that perceives the environment by means of neuromimetic OF sensors. To understand how honeybees may follow a wall [Serres et al., 2008, *Naturwissenschaften*, 95(10), 1181-1187], center along a corridor and adjust their speed to the corridor width [Srinivasan et al., 1996, *J. Exp. Biol.*, 199, 237-244], we developed a vision-based autopilot, which consists of a dual OF regulator controlling the hovercraft's translations [Serres et al., 2008, *Autom. Rob.*, 25(1-2), 103-122]. Yaw disturbances introduce adverse rotational OF component, which do not depend on the distance to obstacles. The robot's gaze therefore requires to be stabilized in yaw to make sure the robot will measure only the translational OF component, as suggested by several insects [Wagner, 1986, *Phil. Trans. R. Soc. Lond. B*, 337, 527-551; Boeddeker & Hemmi, 2010, *Phil. Trans. R. Soc. Lond. B*, 277(1685), 1209-1217; Zeil et al., 2008, *Current Biol.*, 18(8), 320-323]. Our biorobotic approach allowed us to better appreciate the fundamental role of gaze locking in flying animals.

Embedded eyetrackers: Models and implementations

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Despite many years of research [Cogain, www.cogain.org; Hansens et al., 2010, IEEE PAMI, 32(3)], eye detection and tracking is still a challenging problem. This is probably due to the complexity of the biologically plausible models (system and computational models) which are often used to guide the design of new eye trackers. Indeed, an artificial eye tracker should manage inter-individual variability of eyes, eye occlusions, variability in acquisition conditions (3D motion, location, scene illumination, scene occlusion), characteristics of the hardware system (static or dynamic/active) and sensor characteristics such as focus, resolution and acquisition speed. This communication analyses the current state-of-the-art in video-based eye detection and tracking and tries to identify future research directions. Two main classes of computational models will be presented: (1) non probabilistic models, often based on feature detection, followed by Ransac fitting; some existing and potential extensions such as constraints on types of eye movements will be considered; and (2) probabilistic methods based on Sequential Monte Carlo approaches; these methods include particle filters and their extensions which take into account the physiological constraints of eye movements or which combine simultaneous detection and tracking.

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Compact parallel kinematic manipulators to mimic human eye movements

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A high amount of information about people and their neighborhood can be retrieved by the examination of images acquired from a first-person perspective. Aligning a camera continuously with the user's line of sight enables us to record stabilized high quality images even during dynamic conditions. To allow for such an approach the camera orientation system must be able to mimic or even outreach the high dynamic human eye movements while at the same time being compact and lightweight enough to be mounted on a human's head. Three different camera orientation systems which meet these requirements are introduced. All systems are based on small parallel kinematic manipulators driven by ultrasonic piezo-actuators. In addition to the kinematic and dynamic models, which are used to calculate and optimize the workspace/package ratio as well as to estimate the output capabilities, also different application scenarios are introduced.

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Robotic implementation of human eye movement models

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Eye movements are extremely interesting systems of control and sensory-motor coordination, both in neuroscience and in robotics. In robotics, human eye movement models represent challenging research objectives on the one hand, and they provide, on the other hand, effective principles for increasing robot performance. Saccades are interesting in robotics for their very high speed, reaching $800^\circ/\text{s}$. Vestibulo-ocular reflex (VOR) is an amazing control system, able to close the loop between the vestibular system and the eye muscles in 14 ms. Smooth pursuit has the peculiarity of working only with prediction and provides a very well focused example for predictive behavior in robotics. Finally, the coordination of the different eye movements, including the movements of the head, in gaze movements, represents a very efficient model and stimulating challenge for robotics. We propose a robotic implementation of: saccades, based on models of the generation of saccades in the Superior Colliculus; smooth pursuit, with prediction and learning of the target trajectory, and with catch-up saccades; VOR, integrating visual and vestibular information to stabilize images on the retina; and an integrated system with a decisional module based on a model of basal ganglia, for coordinating the different eye movements and generating gaze movements, in a humanoid robot.

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Vision-based motion generation and recognition for humanoid robots

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Pragmatic techniques for humanoid robot motion generation are generally not inspired by biological motion. However, the anthropomorphic structure of the humanoid robot naturally reveals questions linked to the study of biological systems: typically, the choice of the referential for generating a vision-guided hand-reaching motion. We will directly discuss robotic motion techniques related to vision. A common way to describe and control a motion with robots is to use the so-called task-function formalism: objectives to be fulfilled by the robot are described in properly-chosen small vector spaces (the task spaces), very often directly linked to the sensor output. Numerical methods are then used to compute the motion from the set of active tasks. The use of these methods for motion generation will be exemplified by detailing the generation of a visually-guided object grasping while walking. More recently, we have shown that the same formalism can be used to characterize an observed motion. The second part of the presentation will thus discuss the use of the task-function approach to perform out-of-context motion recognition and disambiguation of similar-looking motions.

Perception, Attention & Memory

Remapping of the line motion illusion across eye movements

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Although motioprocesing has traditionally been studied in terms of retinotopically-defined receptive fields, recent evidence suggests that motion can be perceived in external coordinates. At present it is unclear whether non-retinotopic motion effects involve a transient remapping of retinotopic receptive fields tied to eye movements, craniotopic/spatiotopic receptive fields, or are created by top-down attentional mechanisms. In this study we take advantage of a well known visual illusion (the line motion illusion: LMI), in which a line shown shortly after an high contrast stimulus (inducer) is perceived as expanding away from the inducer position. We measured the strength of LMI both with stable fixation and when participants were asked to perform a 10° saccade during the blank ISI between the inducer and line. A strong motion illusion was found across saccades in spatiotopic coordinates. We varied the timing of the inducer and the saccade cue in order to investigate the influence of saccade programming on the effect. When the inducer was presented near in time to the saccade cue, saccade latencies were longer, saccade amplitudes were shorter and LMI strength was consistently reduced. Together, these results suggest that motion perceived in non-retinotopic coordinates depends on an active, saccade-dependent remapping process

Local and global position information in visual stability

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Intrasaccadic displacements of a saccade target object typically go unnoticed. It is believed that this saccadic suppression is due to the visual system's strong assumption that objects will remain stable across the brief saccadic interruption, in absence of significant counter-evidence. Here, we investigated at what level of visual representation these mechanisms operate. Participants were presented with a sparse grid of homogenously oriented Gabor elements, a vertical section of which could be orthogonally aligned to create a figure-ground segregated line-object. In its vicinity, a green dot was present, to which participants executed a saccade. During the eye movement the dot was removed, to reappear in a displaced position 300ms later. Subjects were to indicate the direction of displacement. Critically, the Gabor grid also underwent position changes during the gaze shift, but was not temporarily removed from the screen. As a consequence it could serve as a spatial reference for the dot displacement. By dissociating the position of the segregated object from the Gabor element positions, we could research the contribution of local and global position to transsaccadic visual stability separately. It was found that global object position dominates over local feature positions; however in absence of a global object, local feature positions do play a minor role in transsaccadic space constancy. The exact dot SOA was of no importance.

Visual contrast sensitivity is largely unaltered during saccades

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Saccadic suppression is a reduction of visual sensitivity during saccadic eye movements and can be mediated by either of two sources. One is a passive process of motion smear accompanied by visual masking exerted by pre- and post-saccadic images. The other is an active process exerted by a neural mechanism that turns off visual processing. Some studies have shown that contrast sensitivity is lower during saccades than under fixation, but these experiments were not designed so as to weigh the differential contribution of active and passive sources of saccadic suppression. We report measurements of psychometric functions for contrast detection using stimuli that are only visible during saccades, thus effectively isolating any visual processing that actually takes place during the saccades and also preventing any pre- and post-saccadic visual masking. We also report measurements of psychometric functions for detection under fixation for stimuli that are comparable in duration and spatio-temporal characteristics to the intrasaccadic retinal stimulus. Whether during saccades or under fixation, the psychometric functions for detection turned out to be very similar, which suggests that contrast processing is largely unaltered during saccades and, thus, that no neural mechanism seems to be actively involved in saccadic suppression.

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Post-saccadic target blanking prevents saccadic suppression of displacement for achromatic but not for chromatic target

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It is known that sensitivity to image displacement is reduced at a time of saccadic eye movements (saccadic suppression of image displacement, SSID). Recent studies found that SSID is degraded when a visual target blanks for a while immediately after a saccade (blinking effect). In the present study, we compared the magnitudes of SSID and the blanking effect for chromatic and achromatic visual targets. The chromatic target was a green Gaussian blob with the standard deviation of 0.5 deg that was isoluminant to the red uniform background while the achromatic target was a white Gaussian on a gray background. We found that displacement thresholds at a time of saccades with target blanking were twice as much as those during fixation for both chromatic and achromatic targets and that presentation of the achromatic target immediately after saccades raised the threshold ratio, however, that of the chromatic target did not. These results suggest that luminance responses to visual images right after saccades play a critical role in accomplishing visual stability across saccades.

Mislocalization pattern in a two-saccade sequence

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Shortly before saccade onset, visual stability is transiently disrupted, and systematic errors of localization judgments occur. Such peri-saccadic mislocalization has only been investigated for saccades targeting a single target, and has commonly been attributed to the upcoming saccade motor feedback that biases visual representation. Here we asked whether parallel saccade planning affects the mislocalization pattern. In addition to a control condition using a single saccade, different two-horizontal-saccade sequence conditions were used in which a to-be-localized bar was flashed around the 1st or the 2nd saccade onset. Visual targets eliciting two-saccade sequences were two isolated targets or spatially extended X-strings (xxxxxxx xxxxxx or xxxxxxxxxxxxxxxx) for which the 2nd saccade could either target or explore the stimulus, implying different codings [e.g. Lavergne et al, 2008, Brain Research, 1245, 82-95]. We expected different mislocalization patterns depending on the saccade rank around which the bar was flashed and the 2nd saccade type (targeting vs exploring). We found that the mislocalization pattern around the 1st saccade onset was affected by the 2nd saccade planning, but not by saccade type. This suggests that for both saccade types, different signals such as the upcoming saccade motor feedback and parallel motor planning affect space representation in visual maps.

Eye movements evaluation in a visual search task with a variable number of distractors

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Eye movements involved in a visual search with a variable number of distractors were studied to determine how the number of distractors affects search strategy (saccade size and temporal duration of the fixations). A visual search task with a number of fixed targets and a number of distractors that vary as the task goes [Jaen et al, 2005, Leukos 1 (4), 27-46], was used. Subjects had to sequentially connect series of natural numbers randomly distributed on a PC display, which also included other numbers as distractors. Different tests using 10, 20 and 30 objectives and 20, 10 and 0 distractors respectively, were repeated for different difficulty levels (varying contrast and size of characters). Results show that the time to complete the task varies almost linearly with the number of objectives. As these increase, larger saccades (>10 degrees) and a larger number of long fixations (>660 ms) were detected in all configurations. A bigger number of distractors increases task-time in each case, and modifies the distribution of saccade sizes and of the fixation times significantly. We conclude that the number of objectives, the main factor in task time is modified by visual difficulty, and under these experimental conditions, the number of distractors seems to modify the search strategy.

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Paving a scan path in visual search

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The way we search our visual environment by means of saccadic eye movements can have a systematic component, which is known to be influenced by several stimulus factors. These factors include the relative distance between search elements and their configuration. In this study we investigated how visual scanning is affected by the element configuration by imposing a path between elements. Subjects were instructed to search for a single target element among several others. The elements were connected by lines forming an ordered search path. If subjects followed this path they would look at each element once, inevitably arriving at the target. However, subjects were not instructed about this. Eye movements were recorded by means of a remote eye tracker (EasyGaze). Subjects were clearly influenced by the offered search path. They frequently followed the imposed path between elements. If subjects deviated from the path, they usually looked at another nearby element and subsequently followed the path from thereon. This behavior made them miss some segments of the path. However, subjects often returned to these skipped segments, suggesting that they have a good search memory. Imposing a search path therefore seems to be one of the contributing factors to systematic visual search.

Visual search performance can be enhanced by instructions that alter eye movements

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Subjects perform better on some visual search tasks when they are instructed to search the display passively (i.e. letting the unique item "pop" into mind) rather than actively [Smilek et al., 2006, *Visual Cognition* 14(4-8), 543-564; Watson et al., 2010, *Psychonomic Bulletin & Review*, 17(4), 543-549]. We have extended this finding by adding an additional neutral instructions condition to establish a baseline result, and by tracking the subjects' eyes during the experiment. The reaction time results of the neutral group suggest that we adopt a more active strategy by default and can be made to improve in this task by following instructions to search more passively. The eye tracking analysis found that the instructions led to systematic differences in the way the subjects searched the display. Whereas the neutral and active instructions led to similar patterns of eye movements, the passive subjects took longer to initiate their first saccade, located the target more quickly, and were faster to make a button press once the target was found. If the passive instructions enhance our search performance by altering eye movements, this has potential implications for real-world search tasks that are primarily carried out by moving the eyes.

Orienting Response

Are there any left-right asymmetries on temporal and spatial parameters of saccadic eye movements?

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The question of hemispheric specialization in saccadic control still remains. Indeed, while some studies have reported shorter latencies for saccades directed to the right visual field than to the left one for right-handers, with no difference for left-handers, others did not report any difference. The lack of consistent results and the methodological differences make it difficult to draw conclusions. However, Kolesnikova and colleagues have recently pointed to a potential role for the leading eye [2010, *Neurosci Behav Physiol*, 40(8), 869-876]. Whereas the great majority only looked at saccade latency, our experiment conducts a systematic investigation of latency, amplitude and dynamic parameters of reactive and voluntary saccades. Subjects were tested in Gap-200, Gap-0, Overlap-600 and antisaccade blocks, the saccade target being presented at 5, 10 or 15° left or right of the central fixation point. Preliminary results on right-handers with right leading eye show that the most important difference concerns the spatial parameters of the saccade rather than the temporal ones. The amplitude was shorter and the velocity slower for saccades directed to the left than to the right. Right-handers and left-handers with left or right leading eye were also tested to determine the respective role of hand preference and leading eye.

Saccade latency during monocular presentation of target and distracting stimuli to the dominant and subdominant eye

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The stimulus choice as a saccadic target includes inhibition of other possible answers, the ones which are meaningless for the current behavior. The aim of this study was to estimate dependence of saccadic latency during stimulation of the dominant and subdominant eye in various conditions of presentation of target and distracting stimuli. Ten healthy subjects took part in the experiment. Peripheral visual stimuli were presented monocularly on the monitor in various spatial combinations. Eye movements were recorded using the electro-oculogram. In most cases, saccade latency was longer by 10-30 ms for the presentation of stimuli to the subdominant eye ($p < 0.05$). Saccade latency and quantity of errors decreased when the distance between target and distracting stimuli was reduced and reached a minimum when stimuli were shown in one visual hemifield at a distance of 5 degrees from each other. The maximum saccadic latency occurred when stimuli were presented in different visual hemifields at a distance of 15 or 20 degrees. The results specify that saccadic latency depends on the brain hemisphere where the primary visual information of the stimulus projects. The leading role of the right hemisphere in a situation of a visual choice is supposed.

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Saccades in response to temporal versus nasal trigger stimuli and the involvement of visual attention

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Neural projections from the nasal hemiretina to midbrain saccade control centers are stronger than from the temporal hemiretina. Whether this translates into an advantage for saccade latencies for stimuli projected to the nasal hemiretina is debated. In some paradigms where such an asymmetry has been reported, attention has been taxed, consistent with reports of an advantage for attention shifts to nasal stimuli following invalid cues. We comprehensively investigated whether any such nasal hemiretina advantages exist, testing monocular presentation of nasal and temporal stimuli under a variety of conditions. Saccades with amplitude of 5°, 8° and 20° from center to periphery as well as large (10°) eye movements across the vertical meridian did not result in any asymmetries as latencies were comparable for nasal and temporal trigger stimuli. Neither saccades, performed along with the added load of a secondary discrimination task, nor saccades to triggers preceded by peripheral valid or invalid cues, resulted in any nasal/temporal asymmetries. We conclude that there are no latency differences between saccades in response to nasal versus temporal saccade triggers. These results raise pressing questions regarding attention and eye movements, given demonstrated nasal/temporal asymmetries for attentional orienting and strong evidence for a tight link between attentional orienting and saccadic eye movements..

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Changes in saccadic peak velocity induced by reinforcement learning

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Purpose: Recent results suggest that the relationship between saccadic amplitude and velocity is not always stereotypical. Saccades to target locations associated with a reward [Takikawa et al. 2002, *Experimental Brain Research*, 142:284-291] or saccades to a target related to a discrimination task [Montagnini and Chelazzi 2005, *Vision Research*, 45:3391-3401] have higher velocities than control movements. The value of visual information might also have an influence on saccade velocity [Xu-Wilson et al, 2009, *Experimental Brain Research*, 196:475-481]. Here we ask whether saccadic velocity may be controlled by operant conditioning. **Methods:** Five subjects made saccades to a stepped target. In a first experiment (n=3), a tone signaling points was delivered when the peak velocity was higher than the 60th percentile (based on the 100 preceding saccades). In a second experiment (n=2), the tone was delivered when the peak velocity was lower than the 40th percentile. **Results:** Peak velocity increased by about 14% in the first experiment and decreased by about 12% in the second experiment while saccade amplitudes remained mostly unchanged. **Conclusions:** The ability to reinforce specific peak velocities is consistent with previous studies probing the effects of operant conditioning of saccades [Madelain et al, *Behav Proc* doi:10.1016/j.beproc.2011.02.009].

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Modeling cerebellar contribution to saccade dynamics

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Previous studies quantified effects of temporary inactivation of the fastigial output region (FOR) on saccade dynamics mainly by effects on amplitude and peak velocity. We extend these methods by additional consideration of skewness and duration. Data from horizontal saccades of four different monkeys, acquired in previous studies [Robinson et al., 1993, *J.Neurophysiol.*, 70, 1741-1758; Straube et al., 2009, *Ann.N.Y.Acad.Sci.*, 1164, 119-126] were reanalyzed and fitted by the model of Dean [1995, *Neuroscience*, 68, 1059-1077] explaining the cerebellar influence on saccades by excitatory projections of the FOR on excitatory burst neurons (EBN). The results show that the model parameters (EBN gain and saturation, feedback gain, FOR weights, and onset time of the ipsilateral FOR burst) could account for inter-individual differences of saccade amplitudes, peak velocities, and durations under control conditions, and during unilateral and bilateral FOR inactivation. However, skewness during bilateral FOR inactivation was systematically overestimated by the model. A further drawback of the model is that the error signal of the local feedback loop is not zero at the end of saccades under control conditions. Therefore a more recent saccade model [van Opstal & Goossens, 2008, *Biological Cybernetics*, 98, 561-577] was modified and extended to incorporate cerebellar contributions.

Spatial-temporal encoding of saccade kinematics in the midbrain superior colliculus of macaque monkey

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Saccades have highly stereotyped, nonlinear kinematics. Recent theories suggest that this behavior reflects a deliberate strategy to optimize speed-accuracy tradeoff. Here we argue that the superior colliculus (SC), a key sensorimotor interface in saccade generation, is in an ideal position to implement such an optimization principle. Most previous models attribute the nonlinear saccade kinematics to saturation in the brainstem saccade generator. However, there is little evidence to support this assumption. We now present new evidence for an alternative scheme, which proposes that the nonlinear kinematics reside in the spatial-temporal dynamics of SC activity. We demonstrate a clear spatial gradient in burst properties of saccade-related cells along the rostral-caudal dimension of the motor map: peak firing-rates systematically decrease, while burst durations and skewness systematically increase. Moreover, all recruited cells synchronize their burst profiles, suggesting that the precise burst-timing of a given cell is determined by the planned saccade vector in which it participates, rather than by its anatomical location. Simulations with our linear spike-vector summation model show that these burst properties can fully account for the kinematic nonlinearity of saccades. We propose that the SC acts as the nonlinear, vectorial pulse generator that specifies an optimal straight eye-movement trajectory.

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Role of the fastigial oculomotor region in the control of gaze shifts in the monkey

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The fastigial oculomotor region (FOR) is the output nucleus by which the oculomotor vermis influences the generation of visual-triggered saccades. Its electrical microstimulation elicits saccadic eye movements and its inactivation severely impairs saccade accuracy. Is the FOR involved in the control of eye saccades or does it play a more general role in the control of orienting gaze shifts? To further study this question, we tested the effect of electrical microstimulation and of local muscimol injection in FOR in head-unrestrained monkeys. Long stimulation trains (200-300 ms) evoked gaze shifts that could be ipsilateral or contralateral. These gaze shifts were accomplished by saccadic movements of the eyes. Head movements were evoked at some sites but their amplitudes were very small ($<5^\circ$ in 86% sites; mean=2.4 deg). After unilateral inactivation of the FOR, gaze shifts were dysmetric (ipsilateral hypermetria and contralateral hypometria) and the change in gaze amplitude was mainly due to dysmetric eye saccades for both ipsilesional and contralesional movements. These results suggest that the FOR is involved in controlling the amplitude of eye saccades and not directly in controlling head movements. Further experiments are required to define structures involved in the control of head movements and eye-head coordination.

FMRI multivariate pattern analysis shows saccade-size sensitivity in the human frontal and parietal eye fields

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While saccades towards near and far space are coded by segregated neuronal populations within monkeys' oculomotor brain regions, representation of saccades amplitude has not been demonstrated in the humans brain. Here, we employed two fMRI analysis methods sensitive to neuronal population selectivity at a subvoxel scale: fMRI-adaptation and multivariate pattern analysis (MVPA). We scanned 19 volunteers while they performed visually-guided horizontal saccades in 4-seconds long blocks of either small saccades (4 degrees), large saccades (30 degrees) or saccades of mixed amplitudes (4, 10 and 30 degrees). Each condition was modelled in a general linear model. We performed three analyses, restricted to four bilateral saccades-related regions defined in a meta-analysis. (i) Contrasting small and large or (ii) mixed-size and same-size conditions (adaptation effect) did not show significant effect. (iii) Training linear vector support machines on the voxels parameters estimates associated with small or large saccades in all but one run could predict above chance the size of saccades in the rest of the data in the bilateral parietal regions and medial frontal-eye-fields but not in lateral frontal-eye-fields nor supplementary-eye fields. This evidences, for the first time, a representation of saccades amplitude in the human superior parietal cortex and the medial FEF.

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fMRI BOLD activation by blinks in the periphery of retinotopic visual areas

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We are usually unaware of the rapid and large illumination changes caused by blinks, presumably because of blink suppression mechanisms. In fMRI however, spontaneously occurring blinks trigger large BOLD responses in the visual cortex [Bordier & al., 2010, *Journal of Vision*, 10(7), 902]. Intriguingly, blinks activate mostly the anterior parts of retinotopic visual areas coding the periphery of the visual field. This could be due to the combination of several factors, like a higher sensitivity to luminance changes and transients in the periphery of the visual field, as well as a higher contrast of light changes (including those related to intraocular scattering of light [Stenbacka & Vanni, 2007, *Neuroimage*, 34, 342-348]) against the dark background in the periphery compared to the illuminated center. An additional source of BOLD signal might be the pupil miosis observed after blinks [Hupé & al., 2009, *Journal of Vision*, 9(7), 10.1-19]. Ganglion cells situated at the periphery of the retina are rapidly covered and uncovered by the iris within 1.5s after each blink, leading to OFF and ON responses, possibly contributing to the slow hemodynamic response to blinks at later stages of visual processing, confined to the periphery of retinotopic visual areas.

Gaze & Action

Investigating the effectiveness of manual and gaze cascaded input pointing while performing different tasks

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An alternative computer cursor control method, based on the application of large amplitude gaze shifts of the user, was investigated. Instead of only manual control, a proposed algorithm redefined the cursor to a new place on the computer screen, where the eyesight of the user was directed. Amplitude and velocity of the saccadic eye movement of the user were used as input parameters for cursor repositioning triggers. Two options of the trigger, passive and active, were investigated. During the passive mode, after a saccadic eye movement, the computer cursor was ready to appear at the new location, but was not repositioned at that time, with the purpose not to disturb vision. Supplemental manual input signal was required to trigger repositioning of the computer cursor. During the active mode, the computer cursor was simultaneously repositioned to the location, where the eyesight of the user was directed after a saccade. Experimental investigation of the new alternative method of cursor control was performed using the EyeGaze eye-tracker System (LC Technologies Ltd.) and a software, developed in our laboratory. The parameters of the program were optimized for the most comfortable use. Effectiveness of the alternative cursor control during real visuo-motor tasks was investigated.

Eye and mouse movements in the diagnostics of implicit cognition: Continuous measures make the difference

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The Implicit Association Test (IAT) [Greenwald et al., 1998, *Journal of Personality and Social Psychology*, 74(6), 1464-1480] measures implicit cognition as the relative strength of associations between concepts and attributes. With the test items being categorized according to their concept and attribute categories, the IAT-effect is revealed as longer reaction times for incompatibly combined response categories. However, responses are usually registered as discrete button responses without access to the continuous course of the underlying information processing. In the present study, participants repeatedly solved a Task-Switching Ability IAT [Back et al., 2005, *Experimental Psychology*, 52(3), 167-179]. Responses to these particular IAT items were varied blockwise, consisting of button press, mouse movement or registration of eye movement activity. Compatibility order and response modality were counterbalanced across participants. Our results revealed a robust IAT-effect with no differences between response modalities. More interestingly, response latency, duration and spatial curvature of eye and mouse movements, as continuous measures of information processing, were differentially influenced by compatibility. The results will be discussed focusing on the psychodiagnostic relevance of the continuous eye movement measures.

Role of the finger afferent information and visual feedback in oculo-manual tracking

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The current study aimed to investigate the relative significance of proprioceptive information and visual feedback to tracking maneuver, elaborating on gaze kinematics and its relationship with manual action. Eleven subjects tracked a target moving up-and-down in a sinusoidal manner at 0.5 Hz. Experimental conditions included eye-alone tracking (EA) and combined eye-hand tracking with or without on-line visual feedback (EH and EHM, respectively) of manual performance. In reference to EA tracking, finger action in the EHM condition reduced eye movement excursion, ocular tracking error, and lag time of eye movements. EHM tracking produced fewer saccadic movements of smaller amplitude, but more frequent gaze fixation with longer duration than EA tracking. With on-line visual feedback, subjects in EH tracking could efficiently remedy manual tracking error and lag time, and demonstrated a smaller eye excursion with rare saccade but frequent gaze fixation than in EHM tracking. Most intriguingly, positional error of finger action surged at the presence of saccade in the EH condition, while velocity error surged during EHM tracking. In conclusion, proprioceptive inputs in concomitant eye-hand tracking could modify operation of the oculomotor system in updating visual information. Visual feedback of manual performance empowers error detection and error correction, facilitating sophisticated oculo-manual coordination.

Saccadic inhibition and manual responses

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It is often claimed that saccadic decisions can be used as a case-model to study decision in general. However there may be important differences between competition on oculomotor maps and competition between other types of actions. A critical feature of saccade competition is that visual stimuli have a very rapid and automatic influence. This is demonstrated most dramatically by "saccadic inhibition" [Reingold & Stampe, 2002, *Journal of Cognitive Neuroscience*, 14, 371-388], in which irrelevant visual onsets appearing while an observer plans a saccade produce "dips" in the latency distribution. We tested whether the same phenomenon occurs with manual responses, using the design of Reingold and Stampe (2002). While participants responded to targets on the left or right, large stimuli flashed at the top and bottom of the screen at various delays after the target. We did not observe any "manual dips", suggesting an important difference between oculomotor and manual responses. We propose that visual stimuli have automatic access to saccade plans by virtue of the intrinsic spatial mapping of oculomotor maps. Manual responses do not have such intrinsic mapping, but we predict that rapid automatic influences will occur when such mapping has been pre-established.

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Eye dominance influences differently hand reaction time in left and right handers

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One eye dominates the other. Several studies have shown that visual stimulation of this dominant eye (DE) leads to a faster and greater activation in the ipsilateral hemisphere. We tested whether this could have consequences on visuo-motor processes through a simple hand pointing task. Right and left handers with right or left DE participated in the study. We observed shorter reaction times for the hand contralateral to the DE compared to those for the ipsilateral hand only in left handers. In right handers, the left hand always showed the shorter reaction time, which is consistent with a right hemispheric specialization for spatial attention. Kahn & Crawford (2001; *Vision Research* 41(14), 1743-8) suggested that ocular dominance could reverse as a function of gaze angle. We evaluated in left handers if there was an influence of gaze orientation on hand reaction time but found none. Finally, preliminary supplementary data analysis seems to indicate that eye dominance may influence the difference of reaction time between targets presented in each visual hemifield, a measure allowing us to assess interhemispheric transfer time. Different effects in right and left handers will be discussed in terms of brain lateralization.

Saliency guides covert and overt attention

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We report results of visual search experiments in which the relationship between behavioral response times and oculomotor latencies in feature search task was explored. Observers searched for feature targets differing from distractors (green vertical bars) on the color (a red vertical bar) or orientation (a green tilted bar) or, redundantly, on the color and orientation dimension. In trials with redundant targets, color and orientation signals were presented at the same location (a red tilted bar; single redundant) or at neighboring locations (a red vertical and a green tilted bar; dual redundant). The objective of this study was to compare manual reaction times and saccade latencies for non-redundant and redundant conditions. Manual reaction times to single targets were slower than to single and dual redundant targets. Reaction times to single were faster than to dual redundant targets. The analysis of the latencies of the first saccade after display onset revealed the same pattern as the manual reaction times: saccadic eye movements in single redundant target trials were the fastest, intermediate in dual redundant target trials, and slowest in single target trials. We take this pattern to suggest that behavioral and oculomotor responses are controlled by the same underlying space-based saliency signal.

The Simon effect by visible spatial words: Investigations using eye movements and finger responses

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Spatial stimulus location code impacts on saccades: Pro-saccades towards the stimulus location are faster than anti-saccades away from the stimulus. This is true even if the spatial location is irrelevant for the choice of the correct response (Simon effect). The results are usually ascribed to spatial sensorimotor coupling. However, with finger responses Simon effects can be found with irrelevant spatial word meaning, too. Here we tested and found a Simon effect of spatial word meaning on saccades (Experiment 1 and 3). Results are compared to conditions in which finger responses instead of saccades were required (Experiment 2).

Reading: Visual & Oculomotor Processes

The distribution of fixation durations during reading: Effects of stimulus quality and sentence wrap-up

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Experiment 1 examined the effect of stimulus quality on the distribution of fixation durations during reading. Fixation durations were longer when the entire sentence was faint than when the sentence was presented normally. In addition, reading times were much longer for a single faint word when embedded in normal text, compared to when the entire sentence was faint. In contrast to results from isolated word tasks, stimulus quality affected the mean of the Normal component of the ex-Gaussian distribution, with no effect on the skew of the distribution, regardless of whether one or all words were faint. The results illustrate that stimulus quality can influence fixations of all durations, such that even very short fixations are modulated by stimulus quality. Experiment 2 examined the effect of sentence wrap-up on the distribution of fixation durations. The distribution of fixation durations on sentence-final words were significantly more skewed than fixations on mid-sentence words, even though the overall difference in means was quite small. Together, the two studies illustrate that different sources of processing difficulty can impact on the distribution of fixation durations in very different ways. The findings have important implications for models eye movement control during reading.

Corrective refixations and lexical processing in a variable viewing position paradigm with short time presentation

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Recent evidence investigating the Inverted-Optimal Viewing Position effect (I-OVP) suggested two cohorts of initial fixations: one cohort of short First Fixation Durations (FFD; ~180ms) which are followed by saccades that correct for suboptimal initial fixation and a second cohort which initially fixated at the OVP. The latter showed longer FFD and was - in contrast to the short FFDs - modulated by lexicality. In the present study we use a lexical decision task where participants initially fixated word beginnings, centers or ends (variable viewing position paradigm). Briefly after the presentation, the word and its position was masked (after 10,30,50,70,90,110,130ms). The results show that the lexical decision accuracy was reduced when landing on word-ends in contrast to landing on word-beginnings. The difference in accuracy is accompanied by a higher amount of corrective refixations when landing on word-ends compared to word-beginnings. From this pattern of results two possible interpretations can be derived. First, when assuming an asymmetric attentional span - which was found during reading of sentences - this pattern can be explained by the geometry of the span. In contrast when suggesting a symmetric attentional span these results indicate that during the initial phase of visual word recognition the letters of word-beginnings are of major importance.

The asymmetry of the optimal viewing position: What do you mean hemispheric differences - language specific or not?

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Visual word recognition is faster and more accurate when fixating at a left-of-center position within a word (the optimal viewing position, OVP). Some researchers have attributed the OVP asymmetry to left hemispheric language dominance. OVP asymmetry, however, may not be language specific but reflect a more general property of early visual processing instead. We thus undertook a systematic investigation of the asymmetry of visual processing of stimuli along the horizontal meridian, using non-wordlike materials. Participants were asked to detect a target letter/symbol embedded in a non-wordlike letter/symbol string presented spanning fixation. Both letter and symbolic strings yielded a similar pattern of effects: recognition accuracy dropped-off with target eccentricity and the number of letters in the same visual field as the target (N.VF), more so in the left- than right-VF. The eccentricity by N.VF interaction also was more pronounced in the left-VF: the greater the eccentricity, the more salient the performance drop-off with the number of letters. These asymmetric patterns observed from non-wordlike stimuli reflect hemispheric differences that are not specific to words, suggesting hemispheric differences in the processing of visual stimuli more generally.

Visual and linguistic determinants of the eyes' initial fixation position in reading development

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Two eye-movement experiments with ninety first- through fifth-grade children were conducted to examine the effects of visuomotor and linguistic factors on the recognition of words presented in central vision (using a variable-viewing-position technique) and in parafoveal vision (shifted to the left or right of a central fixation point). For all groups of children, stimulus location had a strong effect on the parameters of basic oculomotor development and lexical-decision time, in both central and parafoveal vision. This effect corresponds to the children's apparent tendency, for peripherally located targets, to reach a position located halfway between the middle and the left edge of the stimulus (preferred landing position), whether saccading to the right or left. For centrally presented targets, refixation probability and lexical-decision time were the lowest near the word's center, suggesting an optimal viewing position (OVP). Note that the first-fixation durations were the longest at this OVP, thus revealing an inverted-OVP [see Vitu et al., 2001, *Vision Research*, 41, 3511-3531]. Word-frequency and lexicality effects were obtained for all groups on gaze duration and lexical-decision time, both in central and parafoveal vision. Possible relationships between these two tasks are discussed with respect to current theories of oculomotor control.

The gap effect and lexical processing

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When a foveal stimulus disappears before the onset of a saccadic target, saccadic latency to the target is reduced. This phenomenon is known as the gap effect. While generally robust, recent research suggests that the gap effect is not present during sentence reading. In the current study, we employed a simple paradigm to further examine lexical processing and the gap effect. In Experiment 1, participants fixated a centrally-presented word that was either high or low in frequency. A target stimulus then appeared in the periphery and participants were required to fixate it as quickly as possible. In the gap condition, the central stimulus disappeared 100 ms before target onset, while in the overlap condition, it remained visible throughout the trial. We found a gap effect, with shorter saccadic latency to the target in the gap condition than in the overlap condition. Experiment 2 was identical to Experiment 1 except that participants were required to read the words in preparation for a subsequent semantic judgment. We found that the saccadic latency to the target was once again shorter in the gap condition than in the overlap condition, demonstrating that the gap effect is present when reading words in isolation.

Reading: Parafoveal Processing

Processing span of word boundary in reading Chinese sentences: A moving window study

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For the Chinese written system, there is no space provided to indicate word boundary. However, many eye movement studies have shown word processing effects in sentence reading. One important issue is how Chinese readers retrieve word boundary information from parafoveal preview. The present study used the moving window paradigm to investigate how far from fixation Chinese readers can identify word boundaries and whether adding word boundary cue would influence the processing of word boundary in parafovea. The gaze-contingent display change technique was employed to manipulate the window size of correctly displayed text from one to four characters to the right of fixation. The results showed that, for cases of word boundary consistent with window boundary, shorter gaze duration and lower refixation probability and regression-out probability were observed than in those inconsistent cases when the window size was only one character to the right. There was no consistency effect found for window sizes of two characters or more. The consistency effect was enhanced for reading text with word boundary cue but did not extend to larger window sizes. The findings suggested that Chinese readers can obtain word boundary information within the area of two characters to the right of fixation.

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Skilled deaf readers have an enhanced perceptual span in reading

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Deaf people typically have great difficulties with reading; on average adult deaf readers read at about the third or fourth grade level and only about 5 percent of deaf individuals leaving high school read at an equal or superior level than their hearing peers. Recent evidence suggests that deaf people have enhanced visual attention to simple stimuli in the parafovea/periphery in comparison to hearing people. It has been suggested that greater availability of parafoveal information could slow down foveal processing resulting in longer fixations and slower reading in deaf signers. We addressed the question as to whether auditory deprivation affects low-level visual processing during reading and compared the perceptual span of deaf signers who were skilled readers to that of skilled hearing readers. Deaf readers were found to have a wider perceptual span relative to skilled hearing readers. Importantly, deaf readers' ability to utilize parafoveal information did not slow foveal processing and lead to longer eye fixations and thus slower reading. These results provide the first evidence that deaf signers' enhanced attentional allocation to the periphery is used during a complex cognitive task such as reading.

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Asymmetries in the perceptual span of Urdu-English bilinguals

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We report an experiment that used a gaze-contingent moving window paradigm to compare the perceptual span during the reading of English and Urdu, which are read from left-to-right and right-to-left, respectively, and so well-suited to revealing effects of reading direction on perceptual span. Bilingual Urdu-English participants read sentences matched for meaning across the two languages that were displayed either normally or blurred so that only text within a window at the point of fixation was normal, and these windows were either symmetrical around fixation or asymmetric and skewed to either the right or left of fixation. The reading times for English showed that performance for asymmetric windows skewed to the right was equivalent to sentences shown normally, and superior to either symmetric windows or asymmetric windows skewed to the left. Conversely, the findings for Urdu revealed that performance for asymmetric windows skewed to the left was equivalent to sentences shown normally, and superior to either symmetric windows or asymmetric windows skewed to the right. The results are discussed in relation to previous findings showing asymmetry in perceptual span is related to the direction of reading in a language [Pollatsek et al., 1981, *Brain and Language*, 14, 174-180].

Preview effect modulated by preview duration in reading Chinese sentences

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Target delay onset time (TDOT) during pre-target viewing was manipulated to investigate the time course of parafoveal preview during Chinese reading. Two-character words were embedded in sentences as the targets. Upon fixating the pre-target, the target was replaced by one of the three types of previews (identical word, unrelated word, or pseudoword) for 60, 120, or 180 ms (TDOT). The target was then presented for the remainder of pre-target viewing and sentence reading. Target gaze durations increased as the TDOT increased. In addition, there was an interaction between preview type and TDOT. The differences between identical previews and non-identical previews were significant in the 180ms condition. Using a linear mixed-effects analysis, the preview effect was shown to increase as TDOT increased. This is a replication of recently published findings that the size of preview benefit is modulated by preview duration. In addition, a similar pattern was also found in our previous study using a boundary paradigm [Yen et al., 2008, *Memory & Cognition*, 36(5), 1033-1045]. Taken together, these results suggest that the source of subsequent preview benefit occurs relatively late during pre-target processing in Chinese reading.

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The orthographic and phonological preview benefit on the eye movements of different Chinese input method readers

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The present study aims to investigate whether typewriting experiences of Chinese readers influence early lexical processing in reading. Chinese is characterized as a logographic writing system in which characters are composed of radicals and strokes and map on syllables. There are two categories of computer input methods for typing Chinese characters. Cang-jie represents the orthography-based input methods which code a character by its constituent radicals and strokes. Zhu-yin represents the sound-based input methods which code a character by the constituent phonetics of its syllable. An eye movement experiment with the boundary paradigm was conducted to examine the orthographic and phonological preview benefit for the Cang-jie and Zhu-yin users. The preview character either orthographically similar or homophonic to target was orthogonally manipulated. The data showed the phonological preview benefit only for orthographically similar characters in the sound-based Zhu-yin users. For orthography-based Cang-jie users, the orthographic preview benefit was obtained and no phonological preview benefit found on early fixation indices. The findings provide the evidence that typewriting experiences of language production affects Chinese readers' early lexical processing in sentence reading.

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Parafoveal-on-foveal effects at the semantic level in a distraction paradigm: Evidence from Chinese reading

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Parafoveal-on-foveal effects, which could be used to provide the evidence about the key controversy in reading, occur when lexical properties of word *n* (parafoveal word) influence processing on word *n-1* (foveal word) during reading. The main goal of this paper was to investigate parafoveal-on-foveal effects in Chinese reading. The studies adopted a new paradigm called distraction paradigm. Using this paradigm, we inserted semantically related and unrelated distraction words *n* which were written in italic type after the target words *n-1* in sentences. The participants were told to ignore the distraction words. The influence of semantic information of one-character word *n* and two-character word *n* on the processing of two-character word *n-1* was explored separately in two studies. The following eye fixation measures were employed: first fixation duration, single fixation duration, gaze duration, duration of final fixation, probability of refixation and skipping. The results showed that the semantic information from the parafoveal character and word could be processed in parallel with the foveal word. The processing of a word would be promoted when the semantic information of the adjacent words inside the perceptual span is related.

Breadth of attention, word length, and n+2 effects

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The nature of word n+2 preview benefits critically informs the evaluation of serial and parallel classes of model of eye movement control during reading. While some studies have reported n+2 effects, these have been criticised for being restricted to cases where word n+1 contained just three-characters [Angele et al, 2008, *Visual Cognition*, 16, 697-707]. The study reported here manipulated whether words n+1, n+2, neither or both were masked while the eye fell on or before word n. The results show that under optimal circumstances - high frequency words in sentences containing a verb-adjective-noun structure - there is clear evidence that word n+2 masking exerts a significant and immediate impact on reading strategies. Across 4 and 6 letter adjectives (word n+1) there were effects of n+2 masking on skipping rate, gaze duration and first pass reading time, with differing effects for the two word lengths. Overall, it is clear that reading strategy interacts with word length and the availability of information from word n+2 and that n+2 effects are certainly not limited to 3 letter words. It appears that attention can be distributed across multiple words simultaneously, but that reading strategies and breadth of attention interact with word length.

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Reading: Development

The preview effect of one- and two-character words for older and younger readers in Chinese reading

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Using the boundary technique, we examined the preview effect for older and younger readers during Chinese sentence reading. The preview of a character was either identical or a pseudo-character. Although the speed of reading for older readers is much slower, the obtained preview effect was almost equal for older and younger readers. However, for younger readers, the preview effect was larger for two-character words, probably due to the incorrect preview being misinterpreted as a one-character word, hence introducing incorrect word length information. And for older readers the differences were not significant. The results were not consistent with Rayner et al. [2010, *Psychology and Aging*, 25(3), 714-718]. The findings suggest that the cognitive strategy was not recessionary for older readers. They need more time to discriminate the words [Laubrock et al., 2006, *Neuroscience & Biobehavioral Reviews*, 30, 872-884].

Interword spacing effects on the acquisition of new words in Chinese second language learners

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We examined the effect of word spacing on people learning to read Chinese as a second language. Specifically, we examined whether spacing facilitated the acquisition of new vocabulary (2-character words). The experiment contained learning and test sessions, with 32 participants who were native English speakers learning Chinese as a second language. In the learning session, we recorded participants' eye movements as they learned Chinese new words embedded in explanatory sentences. Participants were divided into further subgroups - half learned the new words in spaced sentences, and half in unspaced sentences. On a different day, participants returned for the test session where the new words were presented in a different set of sentences; here, all participants read unspaced text. In the learning session, participants who read spaced text read the new words more quickly than those read unspaced text. More importantly, this benefit from the interword spacing was maintained in the test session (unspaced sentences). We conclude that interword spacing facilitates the acquisition of new words, and suggest that there are two possible mechanisms for this facilitation: stronger connections between character and word representations, or more fully specified lexical representations.

Differential effects of word frequency during reading in adults and children: Evidence from eye movements

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While word frequency effects are well-documented in adult readers, these effects are more controversial in children. In two experiments, children's and adults' eye movements were monitored as they read sentences containing high and low frequency words as indexed by counts from either child or adult corpora. Target words were also controlled for Age of Acquisition. Results showed that when child norms were used to index frequency, children but not adults showed longer reading times on low-frequency words. However, when adult norms were used to index frequency, neither age group exhibited robust frequency effects. These results show that while word frequency is a fundamental characteristic in the organization of the lexicon for children, exposure-based learning fundamentally shapes the developing lexicon such that frequency representations change over time. Furthermore, the data show that the frequency with which a word is encountered, independent of the age it was acquired, has a direct impact on the time needed to lexically identify a word in children. Finally, stimuli which are age-appropriate for young children may not induce well-documented effects in adult readers, perhaps due to increased processing ease.

Reading eye movements of Japanese children

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Japanese orthography contains unique characteristics such as a mixture of logographic (kanji) and phonographic (hiragana and katakana) characters, no spaces between words, and the gradual change in text orthography (replacing hiragana with kanji). This study tried to determine whether Japanese orthographies affect the reading eye movements and its developmental change in Japanese elementary school children. The eye movements were recorded for third and fifth graders and adults (N = 22, 25, and 28, respectively) when they read elementary school level texts. For the landing positions of fixations, both the children and adults showed a bias toward the kanji characters within a word, which is consistent with the findings of previous Japanese adult studies. These results imply that the eye movement planning of Japanese readers is developed even if the number of kanji characters in a text is small. In addition, fixation durations decreased with age, which is similar to the findings of other language studies, and the fixation durations for kanji words were longer and slower to develop than those for hiragana words. These results suggest that the gradual introduction of kanji might become a disrupting factor in reading development.

Predicting reading fluency by oculomotor and linguistic skills in Chinese 3rd and 5th graders

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The present study investigated the development of oculomotor control, its influence on reading fluency and on linguistic skills in Chinese 3rd and 5th graders. Thirty 3rd graders and 28 5th graders participated in the experiment. They were tested on reading fluency, character recognition, timed word segmentation skills, and oculomotor control during sentence reading of Chinese. Results showed a significant developmental trend from grade 3 to grade 5. Older children tended to have fewer fixations and shorter fixation durations, with a larger mean saccade length. Both oculomotor skills and linguistic skills predicted reading fluency in grade 5. However, for 3rd graders, only linguistic skills predicted reading fluency, suggesting an as yet insufficient development of their oculomotor skills.

The difference of eye movement patterns between fourth and fifth graders reading social-science textbooks

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Compared to storybooks, social-science textbooks in elementary school usually include many information types, for example, title areas, text areas, and picture areas. Skilled readers move their eyes among these information areas to build richer reading representations. The current study aimed to explore how elementary students read social-science textbooks. Twenty-two students (12 fourth graders and 10 fifth graders in south Taiwan) were recruited for this study. As expected, older students had shorter mean fixation duration (226ms) than younger students (265ms). When we further examined the reading pattern based on the information area, however, we found that there was no age effect in the total fixation duration (TFD). In contrast to the age effect, vocabulary size played a role in the on-line reading process. The results indicated that students with larger vocabulary size had shorter TFD on the text and picture areas than those students with smaller vocabulary size. These results may imply that vocabulary knowledge plays an important role for students' on-line processing. Why the age effect did not occur in the on-line process while elementary students read their social-science textbooks will be discussed.

The role of 'mindless reading' in the development of reading fluency

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We recently developed a string scanning task that has proven useful in capturing visual processing characteristics and eye movement patterns typically found in adult readers. In the 'Landolt scanning task' strings of 'oooo' are arranged similar to a line of text and participants are asked to verify the presence of strings that contain an open target (e.g. 'oocoo'). Eye movements made during this task were compared to normal reading of age appropriate sentences in samples of 3rd and 6th grade elementary school students. Spatial components of oculomotor behavior, like fixation probability and saccade landing positions, were very similar to those in reading. Word viewing time tended to be shorter in scanning, reflecting the higher cognitive workload associated with word processing for developing readers. With binocular coordination, the proportions of aligned, crossed and uncrossed fixations were virtually identical. Ongoing work with a sample of Kindergarten students indicates that some students exhibit very regular reading-like scanning patterns, while others fail to do so completely. We suggest that the non-linguistic Landolt string scanning paradigm can be used with very young readers to examine the visuomotor and attentional dimensions of reading, including binocular coordination and visuomotor "reading readiness" before the beginning of regular instruction.

Children's and adolescent's processing of temporary syntactic ambiguity: An eye movement study

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Previous studies, using spoken input, have suggested that children primarily use structural information when making initial parsing decisions, and that they tend to disregard semantic and contextual information. Participants (N=24, 9-16 years) read a garden path sentence[1,2], and answered a comprehension question (e.g. Did the storm blow the boat?). The design was 2x2 (verb x ambiguity). Verb was optionally transitive or reflexive, and unambiguous sentences contained a comma. Participants also completed assessments of working memory and attention. Eye movements showed an interaction in total reading time and regressions at the disambiguating verb. The interaction was driven by low values in the reflexive-unambiguous condition, suggesting that participants were better able to prevent/overcome the garden path in this condition. There was no difference between ambiguous and unambiguous sentences with optionally-transitive verbs, which indicates that participants attached the ambiguous noun phrase despite the disambiguating comma. Variance in sentence processing was more associated with the ability to control interference, rather than working memory. Our data indicate some reliance on structural information, which implicates a restricted, rather than interactive, processing architecture in children and adolescents.

1.While the storm blew(.) the boat sat in the shed.(Optional-plausible)

2.As Sarah washed(.) the dog ran in the garden.(Reflexive-plausible)

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A scanpath measure reveals effects of age of reader and syntactic complexity of sentences

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Many questions in reading research can be answered using region-based scalar dependent measures such as fixation durations on words or the probability of a fixation on a word. However, these measures fall short in capturing the trajectory of the eyes which is an important notion for some theories of human parsing. Malsburg & Vasishth [in press, *Journal of Memory & Language*] introduced a new measure, called Scasim, that quantifies the mutual similarities among a set of gaze trajectories with respect to their temporal and spatial properties. In order to investigate the sensitivity of this measure, we analyzed eye movements of 222 subjects reading 144 simple German sentences. For every trajectory we calculated how unusual it was compared to the other trajectories recorded for the same sentence. Results: (i) Unusualness is highly correlated with the age of readers. This is consistent with the finding that older readers skip and regress more often. (ii) Sentences with large peaks in surprisal, a probabilistic measure for syntactic processing difficulty, prompt more diverse eye movement patterns. This sensitivity of Scasim to grammatical phenomena as well as to individual differences suggests its usefulness as a tool in reading research.

Scenes

The first eye movements are determined by "perceptive content" of the image

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We exposed observers to 64 test images (TI) with different "perceptive content" (PC) - with simple PC (that were popular advertisements) and with complicated ones (that were pictures of 3D scenes with unusual objects). TI were 18-24° in size and exposed at 300, 600 and 900 ms. Immediately after TI a special post-image (PI) was exposed, which consisted of 81 small digits of different colors and was identical to TI in position and size. The task of the subject (S) (42 Ss participated in the experiment) was to investigate TI visually and to indicate the color and value of the digit just seen. This enabled us to reconstruct the position of a latter eye fixation with an accuracy of 3-4°. The obtained results: 1) Each TI has a few unique points which attract eye movements of all Ss. These points were named "visual attractors" (VA). They were faces, bodies, water reflections, usual and unusual objects, inscriptions [Levashov & Romyantseva, 2006, Perception, v.35, p.86]. 2) TI with simple PC has predictable VA and results in a kind of "scanpath". 3) TI with complicated PC has predictable VA but results in unpredictable eye trajectories.

Viewing multiplex displays: Effects of continuity of content and spatial contiguity on fixation selection

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Multiplex displays are becoming increasingly commonplace in our everyday lives. It is unclear how our extensive knowledge base of single scene inspection can be generalised to multiplex viewing, which may lack the scene continuity and spatial contiguity of its single scene viewing equivalent. We recorded the eye movements of twelve participants viewing scenes that were divided into quadrants and displayed in a normal or random arrangement. The quadrants were either touching (spatially contiguous), or separated by spaces. The tendency to fixate in the centre of the scene was disrupted by introducing gaps between the scenes and by shuffling the quadrants. When the quadrants were presented in the correct arrangement but separated by space, fixations clustered in the corners nearest the screen centre. Viewing shuffled quadrants, participants tended to fixate in the centre of each quadrant, irrespective of the spatial contiguity condition. Viewing behaviour is therefore driven by the overall content of the multiplex display when images are presented in a normal arrangement. When image content is shuffled, observers treat each element as an independent scene, with its own central fixation bias. These results highlight the importance of both scene gist and spatial organisation on eye guidance.

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Influences of instruction on the spatial characteristics of eye movement behaviour in scene perception

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A direct relationship between gaze behaviour and information processing along the dorsal and ventral visual pathways has been suggested in our lab. Based on the combination of fixation durations and saccadic amplitudes a dominance of either ambient or focal processing was identified [Velichkovsky et al., 2005, Proceedings of the XXVII Conference of the Cognitive Science Society, 2283-2288]. The present study aimed to directly manipulate the activity in both streams by providing explicit viewing instructions. Computer-generated abstract scenes, containing abstract geometrical objects, served as stimuli in order to allow for automated and exact matching of gaze allocations to scene objects. Subjects were block-wise instructed to attend either to features of objects (focal processing), their spatial arrangement (ambient processing), or both. Our results confirmed a clear influence of the viewing task on gaze behaviour but not with respect to simple centralized measures such as fixation duration and saccadic amplitude [cf. Castelhana et al., 2009, Journal of Vision, 9(3), 1-15]. Only when spatial aspects of gaze behaviour were considered, i.e. fixation maps and fixation locations in respect to object-background-separation and the time course of both, fundamental differences between the instructions became apparent.

The influence of task complexity on visual attention

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Comparative studies investigating the influence of task on visual attention have mainly focused on standard visual tasks [Castelhana et al., 2009, Journal of Vision, 9(3):6, 1-15] and tasks related to motor-action [Land, 2006, Progress in Retinal and Eye Research, 25, 296-324]; largely neglecting how such tasks compare with linguistically driven tasks [Griffin & Bock, 2000, Psychological Science, 11(4), 274-279]. In this study, we compare visual search, object naming, and scene description, i.e., tasks of increasing complexity in the cross-modal interaction between vision and language required. We find that the synchronization of visual and linguistic information during language processing tasks requires longer fixations and gives rise to higher scan pattern similarity, compared to visual search. In addition, we observe that the spatial distribution of fixations varies significantly across tasks, with naming and search exhibiting more variability than description. Our results extend current research on task comparison by showing that the task complexity has a direct influence on both temporal and spatial aspects of visual processing. In order to arrive at a general theory of goal-directed visual attention, we will therefore need to compare a range of tasks that differ both in their goals and in the cognitive processes involved.

Objects in natural scenes: Do rapid detection and gaze-control utilize the same features?

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To study the effect of image features on attention and perception in natural scenes, two paradigms are frequently used: detection during rapid serial visual presentation (RSVP) and eye-movements during prolonged viewing. It has remained open, however, whether both paradigms, which operate on substantially different timescales, yield similar results. We used the same stimuli in an RSVP task and in a prolonged viewing task. Images could contain either animals or means of transportation as target objects. In RSVP, images were presented for 50ms embedded in a 1s-stream of natural stimuli; in prolonged viewing, images were presented for 3s and eye position was recorded. We find that the probability of detecting a target during RSVP and the probability of fixating the target during prolonged viewing are highly correlated. In some conditions, we increased or decreased luminance contrast (LC) relative to the neutral stimulus. We find that an increase in LC increases target fixations and detection probability. A decrease, however, only worsens detection, but leaves target fixations unaffected. In conclusion, RSVP detection and selection of fixation targets use similar features; during prolonged viewing, however, additional features (e.g., higher-level structure) can drive attention to targets that deviate from expected natural scene statistics.

Gaze control when searching a volumetric space: Comparing eye movement behavior in 2D versus 3D search

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In radiology, computed tomography (CT) has largely replaced the classic x-ray in the detection of lung nodules, a sign of lung cancer. Instead of searching for nodules on isolated 2D images, radiologists now scroll through sequences of images created from 3D volumes of data. While this method undoubtedly provides the observer with greater amounts of information, the search space is also greatly increased compared to single x-rays. How does gaze control change when searching in depth? We placed about 100 realistic, simulated lung nodules into twelve normal, 200-slice chest CT cases. In the 3D condition, non-radiologist observers scrolled through slices, searching for 5 minutes. In the 2D condition, they searched for nodules in individual slices for 7.5 seconds each. We found that searching in 3D was characterized by long periods during which the eyes remained still as observers scrolled through depth. In addition, 3D search included very slow eye movements not observed in 2D search. These appear to be smooth pursuit of lung structures during movement in depth. In 3D search, observers cannot saccade in depth. Scrolling motions may serve as surrogates for eye movements in depth. Observers appear to suspend or modify saccadic movements in XY while moving in Z.

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Contextual cueing in meaningless complex images: The role of semantic information and visual features in learning of familiar contexts

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Previous research using the contextual cueing paradigm has revealed both quantitative and qualitative differences in learning depending on whether repeated contexts are defined by letter arrays or real-world scenes. To clarify the relative contributions of visual features and semantic information likely to account for such differences, the typical contextual cueing procedure was adapted to use meaningless but nevertheless visually complex images. The data in RT and in eye movements show that, like scenes, such repeated contexts can trigger large, stable and explicit cueing effects, and that those effects result from facilitated attentional guidance. Like simpler stimulus arrays, however, those effects were impaired by a sudden change of a repeating image's color scheme at the end of the learning phase (Experiment 1), or when the repeated images were presented in a different and unique color scheme across each presentation (Experiment 2). In both cases, search was driven by explicit memory. Collectively, these results suggest that semantic information is not required for conscious awareness of context-target covariation, but it plays a primary role in overcoming variability in specific features within familiar displays.

Automatic scene exploration mimicking eye saccades

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The aim of this study is to partially reproduce the human visual system behavior by computational and electronic means. When discovering a new scene the human eye processes by saccades. A sequence of focusing points is determined by the visual system in order to explore the whole scene and the gaze rapidly points toward each of those points. Our simulation system is made of an acquisition system and a processing module achieving image processing and driving the acquisition system. The camera acquiring images can move in a spherical way in order to point toward a special point of interest. This point of interest is considered as a focusing point. The first focusing point is chosen at the scene center. The camera points toward this point and then the image is processed to determine the second focusing point, which is the point of highest interest on the current image. These two steps (camera pointing and focusing point determination) are repeated as many times as necessary, in order to scan the whole scene, in a way that simulates the human eye movements. Simulation results are close to those given by a set of human observers.

A reward based visual attention framework for humanoid robots

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Humans are exposed to a vast amount of visual information throughout their interaction with the environment. Among different visual stimuli, finding the ones that are relevant to the task being undertaken is a crucial process. The human vision system employs top-down attention mechanisms that generate eye movements towards task-relevant stimuli [Land & Tatler, 2009, *Looking and Acting*, Oxford University Press]. These attention mechanisms are partly driven by a reward system that makes action-perception associations. A model that derives such relations through reinforcement learning was presented in [Ballard & Hayhoe, 2009, *Visual cognition*, 17(6-7), 1185-1204]. We develop a similar framework using a systems approach in which individual visual processes and cognitive tasks (e.g. visual saliency, motion detection, depth estimation, grasping) are modelled as modules. Distribution of gaze control among different modules to accomplish a certain task is learnt through a reward mechanism. The framework was applied on a scenario using the iCub humanoid robot in a simulation environment where the robot has learnt to look at the relevant objects to support a grasping task.

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Principles of natural vision: How goals and locomotion influence gaze allocation in domestic tasks

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To understand how we visually guide behaviour during natural tasks we need to identify the underlying principles of fixation selection in the context of behavioural goals. Two pervasive principles are: (1) the eyes lead the hands at both the start and the end of interactions with objects; and (2) fixations select (visually unremarkable) locations where objects are about to be placed when being setting down ("guided object putdowns"). Here we examine the sensitivity of these two principles to the overall behavioural goal and to the extent of locomotor activity in the task, following previous speculation that these factors may influence eye-hand latencies and putdowns [Land & Hayhoe, 2001, *Vision Research*, 41, 3559-3565]. We used two different domestic tasks (making tea and sandwiches) under stationary (everything within reach) and locomotive (the participant must move around the environment) conditions. Task influences both the eye-hand latency and frequency of guided object putdowns: with longer latencies and more guided putdowns when making tea than when making sandwiches. These findings demonstrate that ubiquitous principles in fixation selection show sensitivity to task goals. Thus, theoretical understanding of eye movement behaviour in natural tasks must address these differences in the underlying principles of oculomotor behaviour.

Manual affordances bias eye fixations during action planning

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Objects automatically activate the effector suitable for manipulating this object [e.g., Tucker & Ellis, 1998, *Journal of Experimental Psychology: Human Perception & Performance*, 3, 830-846]. For example, a cup with a handle on the right side automatically activates right hand responses. We investigated whether this affordance effect is also present in eye movements towards affordance-defining object parts. Eleven participants saw four objects (hammer, umbrella, pan, mug) on a computer screen. Object orientation was manipulated such that their handles were either on the right or left side. Participants heard between three and eight instructions, each of the form "Move the [object] to [location]". Instructions were then executed by manipulating the objects with a mouse, using the right hand. Consistent with previous work [e.g., Cooper, 1974, *Cognitive Psychology*, 6, 84-107], participants fixated the mentioned objects and locations while passively listening. Importantly, more fixations landed on the objects' handles if the handles were on the right compared to the left side. Similar fixation biases were obtained during subsequent action execution. Since objects were always manipulated with the right hand, we conclude that object affordances not only activate manual effectors but also guide attention towards the affordance-relevant parts of the objects, possibly in support of action simulation.

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Expansion of the central bias, from computer screen to the supermarket

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It has been shown that when presented with a naturalistic scene on a computer monitor, viewers tend to look in the centre of the screen. This central bias occurs irrespectively of both the task and the distribution of features in the scenes. The question that we want to address in this study is whether this finding is restricted to only the computer screen or if it can be translated to just about anything presented in a frame? We investigated this by studying the visual behaviour of consumers making decisions in various settings. Stimuli were presented on a computer monitor, as full size projections on a wall and in a natural setting in a supermarket. We investigated whether consumer eye movements are biased towards the centre in all these environments despite the organisation of the products presented. The results will be discussed in relation to previous findings in consumer decision making and scene perception. Knowledge of central bias in the visual behaviour of consumers has important implications in, e.g., consumer decision making, marketing and retail shelf management.

Influence of the information about the author on the perception and evaluation of paintings

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The current study explores the aesthetic appreciation and evaluation of modern visual art using eye-tracking recordings. Paintings by Salvador Dali and by schizophrenic patients are used. The influence of the information about the author of the paintings is studied in a between-subjects design: all paintings are presented to each participant as belonging either to Dali, or to schizophrenic patients, or without information about the author. Each painting was rated for liking, complexity, abstractness, and brightness of the colors used. It was found that information about the author has influence on all rating scales and also on the time spent in looking at the paintings. Eye-tracking recordings have been used to study the painting zones of interest attended. Analyses of the time course of eye-movements was performed using fixation duration and saccade amplitudes as measures of global vs. focal processing.

Faces & Emotions

Separating superfluous from essential: Which facial region(s) holds the key for expression recognition?

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Communication is the key aspect of everyday life and facial expressions provide the most effective way of non-verbal relations. Human-Computer interactions, social robots, deceit detection and behavior monitoring are some of the potential application areas that can benefit from automatic facial expression recognition. A visual experiment has been conducted in order to find out which facial region(s) is perceptually salient when the human visual system decodes six universal facial expressions i.e. anger, disgust, fear, happiness, sadness and surprise [Ekman, 1971, In J.Cole (Ed.), pp 207-283]. Eye movements of 15 subjects were recorded with an eye-tracker in free viewing conditions as they watched a collection of 54 videos selected from Cohn-Kanade database [Kanade et al., 2000, Fourth IEEE International conference on Automatic face and Gesture Recognition, 46-53]. The results of the experimental study show that the mouth region emerged as salient for the expressions of happiness and surprise while the regions of eyes and mouth captures most of the gazes for the expressions of sadness and fear. Expressions of anger and disgust show the complex interaction of mouth, nose and eyes regions. Results gathered could be used in the development of a biologically plausible framework for automatic facial expression recognition.

The effect of extrafoveal emotional faces on saccade programming

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Converging evidence suggests that humans possess highly specialised neural systems for processing emotional information. Across three experiments, we sought to determine whether extrafoveally presented emotional faces were processed sufficiently rapidly to influence saccade programming. Participants made saccades towards one of two hollow rectangles placed either side of a central fixation cross. The target rectangle was indicated by a brief colour change to its border. On each trial one rectangle contained a neutral face and the other contained an emotional face. The faces were displayed 150ms before or simultaneously with the cue. Participants made faster saccades towards cued rectangles containing emotional compared to neutral faces, and made more erroneous saccades to non-cued rectangles containing emotional compared to neutral faces. Both of these effects occurred at 0 and -150ms SOAs. The effect of emotional faces on prosaccade latency was replicated for faces presented both 4 and 8 degrees away from the central fixation cross. No effects of faces on saccade latencies or errors were observed when the faces were inverted. The results suggest that extrafoveally presented facial emotions are processed sufficiently rapidly to influence saccade programming.

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Does the valence of emotional faces affect eye-tracking measurements?

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Emotion is a "complex psychophysiological experience" which emerges while cognition is influenced by internal and external processes. The aim of this study is to identify the predictors of emotional pictures in young population by using eye-tracking metrics. Forty university students were recruited and randomly assigned to experimental conditions. Forty-eight Emotional face pictures were selected from the Vital Longevity-Face Database according to their valence [Minear & Park, 2004, *Behavior Research Methods*, 36(4), 630-633]. Dependent variables were five types of eye tracking metrics (first fixation length, time to first fixation, fixation length, visit duration, and percentage fixation). The eye tracking data will be collected via Tobii T120 eye-tracking device. The stimuli will be designed on and triggered from E-Prime software. A 2 (gender) x 3 (emotion type) x 2 (age of the people in the pictures) ANOVA will be conducted, with the last two factors as repeated-measure variables. Data collection process is still an on-going process. According to "memory enhancement effect", positive and negative pictures are known to be remembered better than neutral pictures in cognitive psychology literature. In addition, we want to identify the predictors of emotional pictures with eye metrics. This research will shed light on the memory enhancement effect based on eye-tracking metrics.

Eye movements during visual inspection of faces: Interactions between mood induction and face's emotional valence

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We investigated the effects of mood induction (i.e., negative, neutral, positive) on eye movements during a visual inspection task of faces' pictures, which were associated with different valences (i.e., negative, neutral, positive). Each face was presented individually for 15 seconds. Total Fixation Duration (TFD) was generally longer inside Areas of Emotional Interest (AOEIs) - defined as the regions of the eyes and of the mouth -, than outside AOEIs. However this was not the case when participants were under positive or neutral inductions, and that they inspected negative faces. In those latter conditions, TFD inside AOEIs was not different from TFD outside AOEIs. Moreover, under positive mood induction, participants had their number of eye fixations inside AOEIs significantly decreased for negative faces in comparison to what was found for neutral faces. This suggests that individuals who are in positive mood tend to change their visual search so that they avoid searching for information inside AOEIs when these convey negative information. In order to account for these results, we will present a hedonist view of visual search, in which participants self-regulate eye movements as a function of both their own internal state and the nature of the emotions associated to visual stimulation.

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High progesterone levels are associated with enhanced attentional orienting by emotional expressions

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Previous research has suggested that raised progesterone levels in women are associated with an increase in behaviours that might help protect foetal development during pregnancy. To date, most studies investigated recognition accuracy and intensity ratings of facial expressions of emotion across different phases of the menstrual cycle. The current study explored whether attentional orienting to facial expressions of emotion with averted eye gaze is enhanced during the high progesterone phase; characteristic of pregnancy. 28 female participants were tested in their luteal or follicular phase when progesterone was high or low, respectively. Participants were presented with angry, disgusted, fearful, happy, and neutral facial expressions with averted gaze which was spatially congruent or incongruent with an upcoming target. The low progesterone group responded to all facial expressions with similar latencies. However, those in the high group responded with longer latencies to fearful expressions than all other emotions suggesting delayed disengagement from, or a reluctance to respond to, fear-associated stimuli in the environment. Responding to fear might result in potential threat or attack, and therefore avoiding this would help protect foetal development.

What the I's notice: The regulatory role of self-esteem in visual attention

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In three experiments, we employed eye-tracking methodology to test the hypothesis that self-esteem influences attention to positive versus negative stimuli and that the nature of this effect depends on self-concept coherence. For people with a coherent self-concept, self-esteem functions as a standard of self-regulation that biases people's attention in line with evaluative consistency. For people lacking a coherent self-concept, however, self-esteem is vulnerable to disconfirmation and thus biases attention in line with evaluative incongruity. Results provided support for both the consistency and incongruity effects. The results of Experiment 1 provided support for the evaluative consistency effect: among participants with high self-concept clarity, those with high self-esteem tended to gaze longer at positive (happy) than at negative (sad) schematic faces in a memory task, whereas those with low self-esteem tended to gaze longer at negative faces. The results of Experiment 2 and 3, using a different class of stimuli (positive vs. negative adjectives, and pictures of affective scenes), found support for both the consistency and incongruity effects. Results are discussed in terms of the dynamics of the self-structure, the issue of confirmation versus vigilance in self-concept, and the relevance of eye-tracking procedures for investigating basic psychological processes.

Scan paths to faces and relation to social and role functioning in individuals at clinical high risk for psychosis

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Deviant gaze behaviour (GB) is considered as a neurophysiologically determined indicator of visual attention and cognition, prefrontal dysfunction and a potential endophenotype of schizophrenia. Furthermore, GB might contribute to social and role functioning. In order to explore this possible contribution, GB and its association with functional outcome is presented in patients with schizophrenia (SZ), individuals clinically at high risk for psychosis (CR) and healthy controls (HC). Stimuli consisted of standardised facial expressions and were randomised to trials with and without limitation of response time. Fixations within and gazes back to areas of interest (AOI) were significantly less in CR and SZ compared to HC. Furthermore, the proportion of scanning and fixating AOI compared to less meaningful areas was significantly smaller and nearing equal in CR and SZ. These parameters were related to poorer social and role functioning. Our preliminary observations suggest that information gathering and processing of relevant facial features might be ineffective in CR as it has been repeatedly observed in manifest psychosis and beyond that, that GB might contribute to functioning in psychosis and its risk states.

Cognition & Expertise

Effect of expertise and contralateral symmetry on the eye movements of observers while diagnosing Pneumoconiosis

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Pneumoconiosis, a lung disease caused by the inhalation of dust is mainly diagnosed using chest radiographs. It has been shown that contralateral symmetry (CS) of the chest radiographs plays a significant role in Pneumoconiosis diagnosis. Here, we present a gaze tracking study aimed at understanding how the CS information and the expertise effect the eye movements of observers. A task of rating the profusion for lung zones was given to experimental subjects consisting of novices, medical students, residents & staff radiologists, who were presented with 17 double and 16 single lung images. Gaze tracking analysis showed that doctors [residents & staff] move eyes more quickly and over more distances, when compared to that of non-doctors [others]. Fixation time for zones correlates well with an observer's certainty in judgment of the same as definitely normal or abnormal. Left and right lung gaze transitions correlates well with the observer error only in resident radiologists ($r = -0.953$, $p = .047$). Hence, we conclude that for residents, the eye scanning strategies play an important role in using the CS information present in chest radiographs; however, in staff radiologists, peripheral vision or higher level cognitive processes seems to play role in using the CS information.

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Comparison of eye movements between veteran and novice players during one to one defense in American football

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In American football, effective visual information processing is important for players during moments of defense play. We investigated eye movements in predicting the direction of a pass by a defense player. The stimulus of pass by scene including faint motion was presented in a DVD video that was recorded before hand in a real situation in a football field. The following experiments were conducted using 14 male subjects, who were aged around 20 years, with normal vision and physical and mental condition. Seven of them were inexperienced football players (Novice), while the rest had played football as field players for more than two years (Field). Eye movements were recorded by the EMR-8 (NAC) head-mounted system. The subjects were asked to predict the directions of passes. Comparison between Novice and Field showed a horizontal or vertical statistical difference in movements for more than 90 percent in the data. Prediction accuracy rates in the better one were as follows: Field then Novice.

Knowledge versus saliency: What World of Warcraft expert players can tell us?

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This study examines the visual exploration of a dynamic scene between experts and non-experts in the massively multiplayer online role-playing game World of Warcraft (WoW). To do so, we first developed a questionnaire that measures the expertise level in this game. Participants were assigned to two groups (experts vs. non-experts) and were invited to visualize 24 videos according to the following design: Task Instruction (menu vs. character) x Video Complexity (simple vs. complex) x Audio Message (congruent vs. incongruent). After each video presentation, participants were presented with 6 sets of 4-forced-choice recognition task: 5 were related to the video content and 1 related to the audio content. Our preliminary results revealed that expert players have longer saccades and their fixation durations are linearly correlated with video elements semantically salient. Whereas, non-expert players spend more time exploring the scene with fixations more located in the vicinity of the visually salient elements. Experts showed fewer fixations than non-experts ($p < .001$) and with a longer duration ($p < .01$). Finally, experts showed better recognition performance (82%) compared to non-experts (74.5%, $p < .01$). No effect of Video Complexity on either number of fixations or their duration ($p > .1$). Our results are in line with top-down theories of expertise according to which our performance is mainly guided by our prior knowledge about the task.

Visual information perception of expert farmers

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In Japan, most of farmers are getting older and their know-how should be transferred to younger generation, in order to maintain the quality of Japanese agriculture. Farmers manage their crops based on environmental information, condition of crops, etc. For experts, however, this process is so called tacit knowledge and is difficult to verbalize. In order to investigate it, eye movements and utterances of an expert farmer looking around tomatoes in his greenhouse were recorded for four days and compared with the data of farmers with less experience and non-farmers. The results showed that the expert looked at growing points on the top of plants more frequently than farmers with less experience and non-farmers. Interview data suggested that the expert was aware that he focused on growing points, as they reflected the condition of plant and the effect of measures taken. On the other hand, the expert "unexpectedly" also looked at soil at the base of a plant in order to check the amount of moisture. It is concluded that the expert paid attention to whole plants with the main focus on important parts such as growing points by longer fixation, whereas farmers with less experience looked at individual parts of plants by shorter fixation.

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Clinical Aids & Eye Trackers

Testing a mobile cognitive support system for teenagers with autism by a dynamic-interactive eye-tracking methodology

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The objective of HANDS project (Helping Autism-diagnosed teenagers Navigate and Develop Socially) is to develop a partly mobile, partly web-based cognitive support system that helps high-functioning adolescents with autism in social adaptation and development. The present study was aimed at investigating by eye-tracking if the visual user interface of the HANDS Mobile system was successfully designed and developed according to the specific attentional/perceptual needs and limitations of autism. Due to these and other cognitive/behavioural features of autism, a specific methodology had to be developed to fulfil this goal. We tested the mobile interface on 10 adolescents with autism and 10 age-matched neurotypical control subjects, using a desktop-mounted 120 Hz binocular eye-tracker. Testing methodology was developed in two steps. First, a static-passive stimulus presentation was used, placing subjects into imaginative situations, far from real-life usage circumstances. In the final methodology, subjects solved tasks analogous to real-life ones, with guidance from, and in realistic interaction with the mobile device, in a dynamic-interactive task-space. Our partly quantitative, partly qualitative analyses successfully pointed out critical design features of the user interface. We argue that our dynamic-interactive methodology can serve as a methodological model for testing support devices for other atypical groups as well.

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Hits for kids: The video-based head-impulse test in children

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There is no quantitative test to assess peripheral vestibular function at the bedside in children. In adults, clinical and video-based head-impulses are used for this purpose. Here we validate the video-based head-impulse test (HIT) in children. We assessed 3-18 year-olds who presented to our balance clinic with a chief complaint of vertigo and age-matched healthy subjects with no history or clinical signs of balance disorders. Horizontal head impulses were performed as previously described. Eye movements were recorded with a video-camera, head movements with 6-degree-of-freedom inertial sensors (sampling rate 256 Hz). The gain of the vestibular-ocular reflex (VOR) and thus peripheral vestibular function can be readily assessed with the video-based HIT in children. In healthy subjects, the velocity gain of the VOR at 60ms was 0.99 ± 0.08 (mean \pm standard deviation) for head impulses to the left and 0.96 ± 0.07 for those to the right (no significant side-difference, paired t-test, significance level 0.05). These gains are comparable to those documented for adults. In patients, we documented a peripheral vestibular deficit in an eight-year-old boy with Menière's disease. Head-impulses recorded with video-oculography and inertial sensors are a quick and reliable way to assess peripheral vestibular function in children and adolescents.

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An eye movement test based on a simple computerized system: A pilot study

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Purpose: To develop a simple objective eye movement test for use in clinical practice. **Methods:** Two web cams were set facing and side-on to the subject sitting normally and viewing a 17" laptop at 40 cm. A saccade test was produced in PowerPoint using red/green 5mm stimuli appearing alternately 20cm apart at randomized speed. A circular path pursuit test was similarly designed with the dot at velocity ~ 1.32 rad/s. Five normal subjects and five with amblyopia were recruited. The recorded images were quantitatively and qualitatively measured offline using a transparent grid overlay on the monitor in terms of ability, accuracy, head movement and body movement against controlled calibration set points and the Northeastern State University College of Optometry Oculomotor (NSUCO) Test criteria. **Results:** Unlike subjects with normal vision, the saccade and pursuit capabilities and accuracies were significantly poorer in amblyopes where acuity was poorer than 20/25. Significant differences ($p < 0.05$) were found between amblyopes and controls in saccade and pursuit accuracy. **Conclusion:** This simple computerized test offers an inexpensive objective analysis of eye and body movement that can be reconfirmed, and is suited to use in private practice.

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A 99 dollar head-mounted eye tracker

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Head-mounted eye-trackers are powerful research tools to study attention processes in various contexts. Most existing commercial solutions are still very expensive, limiting the current use of this technology. We present a hardware design to build, at low cost, a camera-based head-mounted eye tracker using two cameras and one infrared LED. A Playstation Eye camera (PEye) is fixed on an eyeglasses frame and positioned under one eye to track its movements. The filter of the PEye is replaced by another one (Optolite 750nm) that blocks the visible light spectrum. The focal length of the PEye needs to be re-adjusted in order to obtain a sharp image of the eye. This is done by increasing the distance between the charge coupled device (CCD) and the lens by a few millimeters. One IR-LED (Osram SFH485P) is installed near the PEye lens to impose an artificial infrared lighting which produces the so-called "dark pupil effect". This is done while respecting the Minimum Safe Working Distance. We positioned a second camera on the front side of the eyeglasses frame. Preliminary tests indicate an accuracy of approximately one degree of visual angle, which makes this tool relevant for many eye-tracking projects.

Optical flow may improve eye-tracking spatial resolution

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We are currently developing an eye-tracker that would allow us to measure fixational eye-movements accurately. To achieve this goal, it is essential that the instrument can guarantee high resolution in both spatial and temporal dimensions, e.g. microsaccades can be as little as 10 ms in duration and 5 minute of arc in distance. After a thorough search of the literature, we found that although great efforts have been made to achieve friendly, robust, remote, calibration-free eye-trackers, little has been done regarding spatial resolution. We developed an optically-realistic artificial eye which was mounted on a goniometer equipped with a 0.01 deg micrometer that allowed us to control precisely its movement, thus enabling us to measure the spatial resolution of eye-detection techniques. We found that using a 640x480 pixels, b&w, CCD camera, the Horn-Schunck optical-flow algorithm can correctly detect and measure up to a 0.01 deg position difference of the artificial eye. We also tested two different ellipse-based eye-detection techniques and found that neither of them could detect this difference. Although these results were confined to a controlled laboratory setting, they suggest that optical flow may be a useful tool to enhance eye-tracking spatial resolution.

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Invited Talk

Deciding where, when and what: Population coding for eye movements in the Superior Colliculus

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A distinctive feature of eye motor control is that each movement is remarkably precise, even though the individual neurons responsible are noisy and broadly tuned. The answer to this apparent conundrum lies in population coding, and a primary site for this mechanism is the superior colliculus. In the 1980s, it was shown by David Sparks and colleagues in a classic set of experiments that the endpoints of saccades are determined by the broad population of active neurons in the superior colliculus, not just the most active ones. The principle relies on the fact that the superior colliculus contains an orderly map of the visual world, and each neuron in this map appears to place a "vote" in favor of its preferred location. Population coding provides a conceptual framework for understanding how several other aspects of eye movements are controlled by the superior colliculus. First, the decision about where to aim the eyes - even in the absence of saccades - depends on the distribution of active neurons in the superior colliculus. If some of the neurons representing the location of the currently foveated target are inactivated, the eyes show a systematic offset from the target, presumably because reading out the activity from a distorted population code provides a biased estimate of where to aim the eyes. Second, the decision about when to move the eyes depends on the population activity across the superior colliculus. For example, neurons in the rostral (foveal) part of the superior colliculus map, which may be active during fixation, also contribute to the generation of microsaccades and small regular saccades, based on their individual tuning for location. The decision to maintain fixation or to orient toward another peripheral target therefore appears to be based on an imbalance of activity across the population, rather than by specific neurons with dedicated motor functions. Third, the decision about what to track with the eyes also depends on the locus of population activity in the superior colliculus. Perturbing activity at particular locations biases the selection of the target for eye movements. This effect holds true for pursuit, as well as for saccades, demonstrating that the activity is related to selecting what to track, and not just selecting the saccade. Finally, recent experiments show that superior colliculus activity is not only involved in the winner-take-all selection of individual targets, but also plays an important role in the weighted integration of peripheral visual signals prior to orienting. Together, these results illustrate the enduring importance and broad applicability of population coding in the superior colliculus for eye motor control.

Symposium - Perceptual effects of predictive remapping: Theories, controversies and mechanisms

Visual attention in the pre-saccadic interval

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The moment just before an eye movement is a turbulent time for the visual system, and for visual attention in particular. A pre-saccadic phenomenon that has received considerable interest is predictive remapping: Neurons in particular visual brain areas respond to stimuli that will be brought into their receptive field, even before the eyes set in motion. This intriguing phenomenon has been linked to the subjective experience of visual stability, but there are many open questions. To date, all studies that have investigated the behavioral effects of predictive remapping have probed only a few locations, and, although the results are generally consistent with predictive remapping, it has proven difficult to rule out alternative explanations, offered by competing models of pre-saccadic processes. To address these concerns, we mapped out the complete spatial distribution of attention in the pre-saccadic interval. In addition, research has focused almost exclusively on peripheral vision. Therefore, we investigated the effect of predictive remapping on foveal vision. We found that stimuli presented in line with, but in the opposite direction of, an impending saccade, caused increased interference with a target presented at fixation, consistent with predictive remapping of foveal vision.

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Trans-saccadic priming in hemianopia: Sighted field sensitivity is boosted by a blind field prime

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In frontal and parietal visual areas FEF and LIP, the majority of cells respond to targets that are about to be brought into their receptive field by an eye movement. This effect, known as remapping, is minimal in V1 [Nakamura & Colby, 2002, Proc. Nat. Acad. Sci]. We explored the role of early visual areas in spatial stability across eye movements. A visual target was presented in the damaged field of a patient with hemianopia due to occipital lesion. When the target was presented just before a saccade, reported awareness was elevated when the saccade would have brought the stimulated location into the intact field, even though the stimulus was removed from the display before saccade began. The presence of a blind-field stimulus before saccade increased sensitivity to a near-threshold sighted-field stimulus shown in the same location after saccade. Accuracy to discriminate the orientation of a dim grating was also elevated when the target was preceded by a pre-saccadic blind field prime in the same location. The results confirm that early visual areas are not necessary for remapping, and demonstrate that remapping boosts perceptual sensitivity in the future retinal positions of targets based on signals generated by impending eye movements.

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Attention and memory across eye movements: Costs of converting from retinotopic to spatiotopic representations

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Much work has focused on how visual information is rapidly updated to maintain spatiotopic representations, often in anticipation of an eye movement. However, this predictive remapping may only be half of the story. Here I will present several lines of evidence suggesting that the updating process is not as fast or efficient as one might expect. In addition to neural evidence showing that both low and higher-level visual cortex represents locations in native retinotopic coordinates, behavioral evidence demonstrates that (1) when attending to a spatiotopic location, a "retinotopic attentional trace" erroneously persists for a brief period of time after an eye movement, and (2) despite our conscious experience of an effortlessly stable spatiotopic world and our lifetime of practice with spatiotopic tasks, spatial memory is actually more precise in raw retinotopic coordinates than in ecologically relevant spatiotopic coordinates.

Predictive neural signals related to eye movements in visual cortex

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Perceptual stability requires changes in visual processing with every eye movement. We are investigating where and when these changes occur in visual cortex. We recorded extracellularly from neurons in the middle temporal (MT), and the medial superior temporal (MST) areas of the macaque brain while the animals were making voluntary or reflexive eye movements. We found that in these neurons, changes in both the firing rate and the local field potentials often preceded actual eye movements, consistent with a predictive code. We have previously shown that many individual neurons in these areas carry eye position signals that predict both the size and the direction of an upcoming saccade. Here we report anticipatory changes in firing rates and local fields before fast eye movements that - on average - led to a reduced perisaccadic firing rate. Importantly, however, these changes were highly variable across individual cells. This suggests that these activity changes are unlikely to serve only as a reduction of the gain of the visual response that could hide the spurious retinal motion generated by the saccade. We are currently investigating whether these complex activity changes may be understood in terms of the remapping of feature selective information across saccades.

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TMS over the parietal cortex impairs the remapping and maintenance of visual saliency maps

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The parietal cortex has been implicated in the updating, after eye movements, of a salience map that is required for coherent visual experience and for the control of visually guided behaviour. I will talk about series of TMS experiments that have examined the role of the parietal cortex in the updating of visual saliency maps. In order to generate a salience map, I employed a paradigm in which an uninformative cue was presented at one object in a display to generate IOR- an inhibitory tag. This tag renders the cued object less salient than others in the display, and that slows subsequent responses to visual transients at its location. The location of IOR is normally updated after a saccade. However, this updating of IOR, after horizontal saccades, was eliminated by TMS over the right, but not the left parietal cortex. This suggests that the right parietal cortex is particularly involved in the remapping of IOR. In a subsequent study, I found converging evidence for a right sided dominance in the remapping of the IOR. I will discuss these findings by comparing the TMS results to behaviour in patients with a lesion to the parietal cortex.

Computational mechanisms of predictive remapping and visual stability

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Cells in many visual areas are retinotopically organized and thus shift with the eyes, posing the question of how we construct our subjective experience of a stable world. While predictive remapping [Duhamel et al., *Science*, 1992, 255, 90-92; Melcher & Colby, 2008, *Trends in Cog. Sci.*, 12, 466-473] and the corollary discharge (CD) to move the eyes [Sommer & Wurtz, 2006, *Nature*, 444, 374-377] have been proposed to provide a potential solution, there exists no clear theory let alone a computational model of how CD and predictive remapping contribute. Based on a realistic systems neuroscience model of area LIP and using CD of eye displacement and proprioceptive eye position as inputs, we show that predictive remapping emerges within a model of coordinate transformation by means of the interaction of feedback and CD. Moreover, we demonstrate the influence of predictive remapping on visual stability as objectified by a suppression of saccadic displacement task [Deubel et al., 1996, *Vision Research*, 36, 985-996]. The model predicts that an absent CD signal leads to a bias negative to saccade direction in SSD. Remapping introduces a feedback loop which stabilizes perisaccadic activity and thus leads to the typical increase in displacement detection threshold.

Reading IV: Foveal & Parafoveal linguistic processing

The activation of phonology and orthography during Chinese sentence reading: Evidence from eye movements

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Two eye-tracking experiments were conducted to examine the role of orthography and phonology on lexical access during Chinese sentence reading. Four types of target words were presented separately in the high-constraint or low-constraint sentence context. The most interesting results were that: (1) In the high-constraint condition, the first fixation durations on the target words as a function of homophonic and orthographically similar type were significantly longer than on the congruent targets and no differences of the first fixation durations existed between the homophonic and orthographic types. (2) In the low-constraint condition, both the first fixation durations and the total fixation durations on the homophonic target words were shorter than on the orthographically similar targets. (3) The word frequency effects were found in the low-constraint condition but not in the high-constraint condition. These results suggest the influences of sentence context on the activation of phonology and orthography during Chinese silent reading.

A reconsideration of the frequency \times predictability interaction on fixation durations during normal reading

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Prior research typically reports that frequency and predictability yield additive effects on fixation duration measures [e.g., Rayner et al., 2004, *Journal of Experimental Psychology: Human Perception and Performance*, 30, 720-730]. Hand et al. [2010, *Journal of Experimental Psychology: Human Perception and Performance*, 36, 1294-1313.] reported globally additive effects of frequency and predictability, but argued that these factors can exert interactive effects - but this interaction is dependent on parafoveal preview. The current study addresses methodological concerns about Hand et al.'s (2010) study. Principally, the high-predictability contexts in Hand et al. were medium-predictability, potentially preventing a frequency \times predictability interaction, as acquisition of parafoveal information is influenced by the frequency and predictability of the parafoveal word [Balota et al., 1985, *Cognitive Psychology*, 17, 364-390; Inhoff & Rayner, 1986, *Perception & Psychophysics*, 40, 431-439]. Comparisons of high- and low-frequency words in very low-predictability and medium-predictability items yielded an additive pattern of effects on fixation durations, consistent with prior research. However, an interactive pattern of effects was demonstrated in global fixation duration analyses when high- and low-frequency words in very low-predictability and very high-predictability contexts were examined. Implications for models of eye movements during reading and theories of language processing are discussed.

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Implications for language models: Fixation and dwell times reveal important predictors for processing multiword units

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Multiword units (MWUs) are frequently co-occurring word strings. They include the following subtypes: idioms (e.g., to pay the piper), restricted collocations (e.g., to pay attention to) and lexical bundles (e.g., to pay by credit card). This study aims to determine whether processing is different for each of the MWU subtypes and, if the subtypes are different, how. Twenty-one native speakers of North American English read 250 sentences, 150 of which contained lexical bundle, restricted collocation, or idiom MWUs in context. Total sentence and word dwell times along with first fixation durations were analysed for each sentence and each MWU. The results indicate that words within MWUs are in semantic competition with the MWUs themselves, and that more than one frequency variable is needed to differentiate the processing of the three MWU types. Further, we see that semantics and frequency variables combined to cause unexpected effects, particularly with respect to function words and individual word frequency. Finally, the effects seen in these results point toward an exemplar-based theory of language processing.

Dissociating effects of lexical parafoveal preprocessing from unrelated influences

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Several corpus studies of reading find an effect of successor word frequency on current word fixation times—lexical parafoveal-on-foveal effects (PoF) [Kliegl et al., 2006, *Journal of Experimental Psychology:General*, 135(1), 12-35]—while studies employing experimental manipulations do not [Rayner et al., 2007, *Journal of Experimental Psychology: Human Perception and Performance*, 33(1), 230-245]. The corpus studies suggest that readers obtain lexical information from the upcoming word before they have finished identifying the current word, while the experimental manipulations shed doubt on this claim. We combined a corpus analysis with a parafoveal modification of the moving mask technique [Rayner & Bertera, 1979, *Science*, 206(4417), 468], so that, either (a) word $n+1$, (b) word $n+2$, (c) both words, or (d) neither word was masked. We found that denying preview for either or both parafoveal words increased average fixation times. Furthermore, we found PoF effects similar to those reported in the corpus studies. Importantly, these PoF effects were found even when the parafoveal word was masked, suggesting that apparent PoF effects may have causes that are correlated with successor frequency, but are unrelated to lexical parafoveal preprocessing. Instead, they might be due to top-down influences (e.g., effects of part of speech or transitional probabilities).

Parafoveal processing in reading: Dissociating distributed sources of preview effects in the boundary paradigm

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Fixation durations during reading are shorter on easy than on difficult words (immediacy effect). They are also shortened by preview benefit (PB) if useful parafoveal preview of the fixated word was gained on earlier fixations. An open question is whether preprocessing parafoveal words also directly affects fixation durations at the fixated word, and if so, whether such parafoveal-on-foveal (POF) effects are genuinely due to distributed processing. Alternatively, oculomotor error could mimic distributed effects by target word processing in a mislocated fixation. In two n+2-boundary experiments, we independently manipulated the pre- and post-boundary difficulty of the target word n+2. This 2x2 design allows us to dissociate immediacy effects, PB and genuine POF effects in a single analysis. Focusing on fixation durations on the short pretarget word n+1, we obtained evidence for a delayed POF effect but not for immediacy and PB effects of processing word n+2 in mislocated fixations on word n+1. In a third experiment we applied the same design to an n+1-boundary paradigm investigating how much of the classic PB effect is in fact due to delayed POF cross-talk. The present results challenge the role of oculomotor error as explanation of distributed processing effects in reading.

Lag and successor effect during mindless reading

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The extent to which lexical properties of words n-1 and n+1 influence fixation durations on word n (i.e., lag and successor effects, respectively) is highly contested [cf., Kliegl et al., 2006, *Journal of Experimental Psychology: General*, 135(1), 12-35; Rayner et al., 2007, *Journal of Experimental Psychology: General*, 136, 520-529]. One explanation of such findings and their intermittent nature is that attention is dynamically modulated during reading, occasionally encompassing multiple words and thereby giving rise to the effects. To examine this possibility, we examined the eye movements of 100 participants reading a novel with instructions to indicate episodes of mindless reading (i.e., lapses of attention during which the eyes continue to move with little or no comprehension; Reichle et al., 2010, *Psychological Science*, 21, 1300-1310). Using analytical methods similar to those of Kliegl et al., we examined lag and successor effects during intervals of mindless versus normal reading. Lag and successor effects were often evident during mindless reading, but absent during normal reading, consistent with the hypothesis that attention is allocated more diffusely during the former and providing an account for why such effects are sometime reported and sometimes not.

Orienting Response II

Hemifield differences in saccade generation

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Visual exploration of natural scenes imposes demands that systematically differ between the upper and the lower visual hemifield. Yet little is known about how visual performance is affected by the location of visual stimuli or the direction of a behavioural response. To investigate this we compared saccadic reaction times between upper and lower hemifield with paradigms involving express saccades (fast reflexive saccades), regular latency prosaccades, saccades toward weak stimuli, antisaccades, saccades to memorized targets and saccades toward compound stimuli. We found that latency of express saccades seems similar in the upper and the lower hemifield. All other saccade types, independent of whether they are directed toward a real, a memorized or a computed target, exhibit a shorter latency if aiming toward the upper hemifield as compared to the lower hemifield. This upper field advantage for reaction times does not depend on visual perception; it possibly originates upstream of the saccadic gaze centres in the midbrain. The fact that this advantage is so robustly present in a variety of different tasks suggests that it is a general feature of saccadic programming.

Enhanced fixation activity reduces remote-distractor and global effects

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Fixation vs. saccadic behaviour is enabled by reciprocal activity between rostral and caudal regions of the motor map of the Superior Colliculus. Whether this is relayed by rostral-to-caudal inhibitions, and hence lateral interactions or the competition between "Fixation" and "Move" neurons/systems remains undetermined. Here, we show in line with the lateral-interaction hypothesis, that an accrued level of fixation-related activity reduces the impact of a peripheral distractor on saccades to a peripheral target. On each trial, a singleton target appeared with or without a less eccentric ipsilateral distractor; both the eccentricity of the distractor and the angular separation between distractor and target varied. Stimulus presentation was simultaneous to fixation-stimulus offset, but in two of three conditions, an additional, foveal distractor was displayed; this was either smaller or larger than the cumulated size of distractor and target in collicular space, thus given the Cortical Magnification Factor. Results showed that saccade onset was delayed when the target appeared with (as opposed to without) a remote distractor, but only in no-foveal-distractor conditions. Furthermore, the tendency for the eyes to land between proximal stimuli (or global effect) greatly reduced with foveal stimulation, and this was not entirely due to the overall increase of saccade latency in foveal-distractor conditions.

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Influence of temporal target expectation on saccade initiation

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Saccade initiation is classically assumed to rely on the reciprocal decrease of neural activity related to fixation and increase of neural activity related to movement. These visually-triggered mechanisms are presumed to unfold optimally when the delay separating the extinction of the fixation and the presentation of the target stimulus (i.e., the gap duration) is around 200 ms. However, temporal expectation of the onset of the upcoming stimulus influences preparation for action, as evidenced on manual reaction times. Here, we investigated the interplay between such top-down and bottom-up mechanisms in saccade generation by testing whether temporal expectation of the target onset affects saccade initiation. We manipulated temporal target expectation by varying the gap duration (200 vs. 600 ms) either within blocks of trials or in separate blocks. When the gap duration was varied in separate blocks, saccadic reaction times were shorter for 200 ms than for 600 ms gap duration, replicating previous findings. The gain in reaction time for the 200 ms gap duration was reduced when the gap duration was varied within blocks, revealing an effect of temporal target expectation on saccade initiation. These results suggest that the dynamics of the neural mechanisms pertaining to fixation and movement is task dependent.

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Feed forward versus feedback competition in saccadic target selection

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Humans have evolved a highly efficient saccadic search process. The neural process that selects a goal for the next saccade is believed to operate on a 'target salience map'. Under natural conditions, many targets compete for selection. This competition may involve cross-inhibition by feedforward connections (i.e., signals related to the competing stimuli), or signals related to the output (i.e., the upcoming saccade signals). How can we distinguish between feedforward and feedback competition? The key is the effect of changing stimulus salience. Feedforward cross-inhibition between two simultaneously (<200ms) presented targets, will promote choice of the stimulus with the highest final level. A network with feedback cross-inhibition, however, will stabilize into a dominant choice for the initially stronger of two competing stimuli even when the stimulus strengths are reversed later on. This holds because the initial 'winner' maintains its advantage by suppression of the input of the competing channel. To test these predictions, we investigated the effect on saccadic choice probability of breaking the stimulus ambiguity briefly by a small contrast step early or late during saccade preparation. Eye movements were recorded with scleral search coils. Our findings support the notion that target selection processes rely on feedback rather than feedforward cross-inhibition.

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The Global Effect for antisaccades

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Prosaccades are displaced towards a distractor that is near a target - "global effect (GE)". This is thought to reflect averaging of neural activity in a collicular map. In antisaccades, a subject looks away from a suddenly appearing target. Weaker activity is generated in the colliculus and a spatial dissociation between the loci of stimulus-related and motor-related activity is created. All trials were with or without a distractor, and randomized within block. 1) GE: Antisaccades Vs prosaccades: 12 subjects performed prosaccades and antisaccades in separate blocks. Distractors: near, far, upper or lower. We found that the GE in antisaccades is similar in magnitude to the GE in prosaccades, inconsistent with collicular predictions. 2) GE: Stimulus Vs motor distractors: 12 subjects performed two blocks of antisaccades. Distractors: same set of locations as above. In one block, the distractors appeared on the goal side while in the other they appeared on the stimulus side. Next, 12 subjects performed another experiment with 2 similar blocks. The target had 10 possible locations, vertically centered. Distractors: near or far. We found GE only for goal distractors, indicating that GE emerges from interactions with motor representations rather than stimulus maps.

Impaired volitional saccade generation as a candidate endophenotype for obsessive-compulsive disorder?

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To investigate cognitive dysfunctions in psychiatric patients, oculomotor tasks are well suited as they only address a small number of cognitive functions and allow their experimentally controlled variation. In patients with obsessive-compulsive disorder (OCD), clinical observations of repetitive behaviours suggest dysfunctional volitional action generation. In fact, by using centrally cued saccade tasks, we recently showed impaired volitional saccade generation in OCD patients. Yet, it is still unknown whether these dysfunctions can also be found in symptom-free subjects at a heightened risk for OCD (unaffected first-degree relatives) thereby reflecting a putative endophenotype for OCD. Hence, the present study used centrally instructed saccades to assess volitional saccade generation in OCD patients, unaffected first-degree relatives and healthy controls. Preliminary analysis of 22 subjects per group (unmedicated patients with matched relatives and controls) revealed significantly slowed volitional saccade generation in patients and relatives compared to controls. To sum, this is the first study showing impaired volitional saccade generation in unaffected first-degree relatives of OC-patients. Impaired volitional saccade generation might therefore represent a candidate endophenotype for OCD: a liability index or mediator between the pathway from genetic risk or environmental traumas to OCD.

Symposium - Perception of dynamic scenes

Gaze guidance in dynamic natural scenes

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The message that is conveyed by an image or movie is not only determined by its colour and brightness, but also by the eye movements made by an observer to sample the image. Over recent years, we have developed algorithms and systems to apply gaze-contingent low-level transformations to videos in order to influence the scanpath of an observer, and thus change the message that is communicated. I will first describe our model of low-level saliency that predicts eye movements in dynamic natural scenes better than state-of-the-art algorithms. An important finding concerns the temporal relationship of dynamic salient events and corresponding eye movements; natural scenes differ qualitatively from more synthetic stimulus types (TV shows, video games). Based on the saliency model, we derived transformation rules of how to locally modify the spatio-temporal frequency bands of a movie in order to make movie regions more or less salient. We then implemented the necessary filtering operations on the GPU with very low latency and as a function of gaze direction. Finally, I will present results for more than 100 subjects on how gaze behaviour is changed when the saliency distribution of natural videos is modified in real time on a gaze-contingent display.

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Foveating instructional videos based on experts' eye movements to teach perception and interpretation of dynamic scenes

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Tasks based on perceiving dynamic scenes, like medical diagnosis of patient videos, require not only conceptual knowledge of the task but also skills to visually search for relevant areas and interpret these observations. This study applied a novel instructional method to teach these skills by showing how an expert perceives and interprets videos of patients (eye movement modelling examples; EMMEs). These videos were verbally explained by the expert (control condition) and presented to students. In the experimental conditions, the students received a recording of the expert's eye movements superimposed on the videos displayed either as a circle (circle condition) or by blurring the areas the expert did not focus on (foveation condition). Compared to the other two conditions, results show that foveating the videos guides the students' eye movements most. Moreover, when presenting the students videos of new patients without any guidance, participants studying foveated EMMEs looked faster at relevant AOIs and had higher total dwell times on relevant AOIs. Furthermore, these participants showed enhanced interpretation performance of the relevant areas in contrast to participants in either the circle or the control condition. These findings show that foveated EMMEs can successfully convey medical diagnosis based on perceiving dynamic scenes.

Development of oculomotor control in infants during film viewing

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Twelve months after birth, electrophysiological work has shown alerting/orienting systems involving subcortical and parietal areas to be relatively mature, whereas executive systems involving anterior cingulate and prefrontal areas are still relatively rudimentary [Johnson et al., 2001, *Developmental Neuropsychology*, 19, 295-323]. Studying spontaneous infant viewing tendencies of dynamic scenes offers an opportunity to study the relative importance of exogenous/endogenous orienting systems in a system that is still 'being built'. In part one, we discuss the methodological challenges presented by obtaining infant viewing data precise enough for low-level saccadic parameters to be examined. We discuss adaptations we have made to standard fixation detection and interpolation algorithms and artifact rejection techniques to make them appropriate for use on the lower temporal resolution and more fragmentary data obtained from eyetrackers that can be used with infants. In part two, we present data from a study in which one-year-old infants viewed a variety of complex and non-complex still and dynamic images and also completed a battery of standard psychometric assessments including attentional disengagement latencies and cognitive control, as well as data from various at-risk groups. We discuss whether it is possible to use free-viewing data to assess individual and between-group differences.

Social context and dynamic scenes

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We have investigated who is fixated in a social scene, where on the face people look, and how this changes according to the perceiver, the stimulus and their task. In our first experiment, participants watched a video of people giving their views. One speaker made a potentially offensive remark. If participants believed these remarks could be heard by others, they fixated individuals who were likely to be offended. We interpret these findings in light of the social indexing hypothesis: that cognitive processing is served by an attentional mechanism that uses social knowledge to identify, moment by moment, the most relevant people in our environment. In other experiments, we quantified whether participants looked at the eyes of mouth of speakers. We found distinct gaze differences between subgroups of participants with autism spectrum disorder. In a normal population, eye-mouth differences were produced by the angle of the camera (directly facing speaker or to the side), social context (whether she was speaking to a person or a tape recorder) and participants' task (suppressing emotions or not). In short, we find that the simple story about social perception - that people look at a speaker's eyes unless they are autistic - needs substantial revision.

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Perceiving dynamic movie scenes and natural environments

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The role played by film and video is enormous, as a source of narrative, a means of persuasion, and as simple entertainment. Movies offer clear advantages over static images as experimental surrogates for real world viewing conditions because they capture the dynamics of natural environments. They also have the advantage of allowing for the necessary degree of control demanded by psychological experimentation. Recent models of eye movement behaviour have been derived from video-based studies and show good explanatory abilities. However, stimulus changes occur in film (indeed, they are ubiquitous) that could never occur in the real world: an editorial cut can transport the viewer instantaneously to a new location in the scene. In this talk we review evidence from our lab and others about the oculomotor and memorial consequences of editorial cuts. Both eye movement behaviour and explicit object memory show that viewpoint changes selectively impair spatial understanding of the objects in the background of the movie. Editorial cuts therefore present specific challenges for our spatial understanding of scenes, which may not be present in natural settings. We discuss the implications of these findings with regard to the similarities and differences between movie perception and perception in natural settings.

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Going with the flow? The endogenous/exogenous influences on gaze control in dynamic scenes

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Where does one attend when viewing dynamic scenes? Unlike static scenes, the inclusion of transients such as motion and the flow of information in a dynamic scene may result in a greater exogenous control of attention but also necessitate moment-by-moment endogenous guidance in order to filter out irrelevant visual events. These factors were investigated in a series of studies recording the eye movements of participants whilst they watched a range of composed (e.g. TV and film) and naturalistic dynamic scenes under different viewing tasks. The best low-level predictor of gaze allocation during free-viewing of dynamic scenes is motion and motion contrast predicts the degree of clustering of gaze across multiple viewers. However, this bias towards motion can be overridden by viewing tasks that prioritise static features such as background, e.g. recognise the location. Gaze behaviour whilst free-viewing dynamic scenes depicting people engaged in recognisable events (e.g. doing the laundry) suggest that attention to motion may not be evidence of exogenous capture but rather a moment-by-moment interaction between motion, the semantic structure of naturalistic events and higher-order factors such as familiarity, memory and expectation.

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Symposium - Microsaccades: Physiology, behavior and modelling

Neural mechanisms for microsaccade generation: The role of the superior colliculus

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The behavioral characteristics of microsaccades have been studied extensively. However, the neural mechanisms for generating these movements are less understood. Here, I describe recent investigations of such mechanisms. Microsaccades have long been known to be driven by pre-motor and motor commands that drive saccades. However, whether microsaccades are also under the influence of higher-level processes that affect saccade generation was unclear. We recently found that the superior colliculus (SC), a structure implicated in selecting saccade target locations, also plays a role in generating microsaccades. Microsaccade-related SC activity is characterized by a gradual increase in firing rate starting ~100 ms prior to microsaccade onset, a peak of discharge just after movement onset, and a subsequent gradual decrease in activity until ~100 ms later. These properties are shared with saccade-related neurons, suggesting that in the SC, neuronal generation of microsaccades is similar to that for larger saccades. In addition, SC inactivation reduces microsaccade frequency and alters eye position, in a manner consistent with the SC's putative role in defining behaviorally-relevant goal locations for different types of eye movements. Our results shed new light on the role of microsaccades, and they also provide a basis for understanding these movements' interactions with high-level cognition.

Response timing in the lateral geniculate nucleus around fixational saccades

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Much attention has been given to changes in response amplitudes around the times of saccades. In the alert macaque lateral geniculate nucleus (LGN), amplitude decreases during about 200 ms around fixational saccades. But timing changes can also have important consequences for visual processing. Responses are retarded during a similar 200 ms period. Both parvocellular and magnocellular neurons show this behavior. The timing changes consist of phase lags at low temporal frequencies, which implies that latencies shorten around saccades. These results are consistent with several consequences for cortical physiology and psychophysics. For example, cortical neurons can maintain adequate responses to drifting stimuli despite the jumps of discrete stimuli across their receptive fields caused by saccades, as the temporal shift observed in LGN compensates for the spatial shift evoked by the saccade. Temporal compression [Morrone et al., 2005, *Nature Neuroscience*, 8(7), 950-954; Binda et al., 2009, *Journal of Neuroscience*, 29(42), 13147-13157] could be produced by these LGN timing changes, including the reversal in time perception seen by these authors about 70 ms before saccades, that could be due to a sharp shortening of latencies.

Knights Templar Educational Foundation, GHSU Vision Discovery Institute

Visual contributions of microsaccades in high-acuity tasks

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We have recently reported that, during execution of a high-acuity visuomotor task, microsaccades (a) precisely move the eye to nearby regions of interest, (b) are dynamically modulated by the ongoing demands of the task, and (c) exhibit suboptimal exploration strategies when the task is not successfully accomplished (Ko et al., 2010, *Nature Neuroscience*, 13, 1549-1553). These results support the long-standing proposal that microsaccades enable exploration of small regions in the scene in the same way saccades are normally used to scan larger regions. Microsaccades may facilitate examination of fine spatial detail both by generating transients in neural responses and by enabling examination of the stimulus with a retinal region well-suited to the task. Although visual resolution is often assumed to be constant within the fovea, non-uniform foveal vision is predicted by retinal anatomy. Here, we compared performances in high-acuity judgments when eccentric stimuli were examined in the presence and absence of microsaccades. Discrimination of stimuli at eccentricities as small as 9° was significantly better in trials in which microsaccades shifted the preferred retinal location toward the stimulus than under retinal stabilization. These results suggest that one of the functions of microsaccades is to compensate for heterogeneous visual capabilities within the fovea.

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Interaction between microsaccades and saccade latencies in scene viewing

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Saccade latencies are shortened for 1/f-structured background compared to uniform background [White, et al., 2008, *Current Biology*, 18, 124-128] at equal levels of target visibility. This effect is known as the saccadic facilitation effect. We show that microsaccades are modulated by background texture. After a display change, structured backgrounds induce a stronger decrease of microsaccade rates than uniform backgrounds. The occurrence of a microsaccade within a certain time window can delay a subsequent saccadic response. Taken together, the inhibition of microsaccades in structured backgrounds can result in short saccade latencies and, therefore, contribute to the saccadic facilitation effect.

A unified model for drift and microsaccades

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Stabilization of the retinal images leads to a very rapid (<200 ms) decline in photoreceptor response and a fast loss of visibility of stabilized stimuli. A possible role of fixational eye movements can be to counteract this retinal bleaching and to enhance the visibility of static objects. Here we present a computational model describing simultaneously drifts and microsaccades motivated by a random walk in a swamp, with sinking tiles as long as the walker stays on them, jumps of the walker to the highest neighboring tile, and a recovery of unvisited tiles. The depth of each tile represents the level of fatigue at the retinal site. Three further assumptions are incorporated: First, overall fixation is confined by a quadratic potential. Second, if all neighboring photoreceptors are below a certain threshold the walker jumps to the globally least fatigued photoreceptor (generation of microsaccades). Third, an oculomotor potential mediates the microsaccade direction. The model nicely reproduces several properties of drift and microsaccades, i.e. scaling exponent transition from persistent to anti-persistent behavior, inter-microsaccade interval distribution, angular distribution of microsaccades and reduced retinal image slip prior to microsaccades.

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A hyperacute optical position sensing device based on eye tremor

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We have designed and built a simple optical position sensor inspired by the tremor eye movements observed in many vertebrate and invertebrate animals. In the elementary version presented here, the sensor relies on the repetitive micro-translations of a pair of photoreceptors set behind a small lens, and on the specific processing from the two photoreceptor signals [Viollet & Franceschini, 2005, *Rob. and Auton. Sys.*, 50(4),147-161; Viollet & Franceschini, 2010, *Sensors and Actuators*, 160, 60-68]. Retinal micro-scanning was performed via a small piezo-bender actuator driven at a frequency of 40Hz. The sensor was found to be able to locate a contrasting edge with an outstandingly high resolution 900-fold greater than its static resolution (which is constrained by the interreceptor angle), regardless of the scanning law imposed on the retina [Kerhuel et al., 2011, *IEEE Sensors*, in press]. Hyperacuity is thus obtained at low cost, thus opening new vistas for the accurate visuo-motor control of robotic platforms. The simplicity, small size, low mass and low power consumption of this optical sensor make it highly suitable for applications in the fields of metrology, robotics, astronomy, automotive, and aerospace engineering. The operating principle may also shed new light on the whys and wherefores of the tremor eye movements occurring in both animals and humans.

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Scenes IV: Foveal / Peripheral & Local / Global processing

Central and peripheral masking and the encoding of scene information: The mask-onset delay paradigm

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In a variant of the mask-onset delay paradigm, subjects viewed full-color real-world scenes with instructions to memorize them (Experiment 1a) or to search for a target object (Experiment 1b). After a fixed interval following the onset of each eye fixation (50ms, 75ms, or 100ms), either the area in the central visual field was masked, or else the entire scene was masked. The mask was removed when the subject made an eye movement. In the central masking condition, subjects' task performance was largely unaffected even at the shortest mask-onset interval. In contrast, when the entire display was masked, task performance was impaired even at the longest mask-onset interval. We also included control conditions in which the display change constituted an increase in luminance rather than the application of a mask, which allowed us to tease apart the effects of processing disruption due to the mask and those due to saccadic inhibition resulting from the display change. Our findings demonstrate that the processing of scene information in the service of high-level viewing tasks can proceed normally when scene information is available in central vision for only 50ms within a fixation, provided that peripheral information remains visible.

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The contributions of foveal versus extrafoveal vision to visual search in real-world scenes: Evidence from eye movements

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What is more important when searching for an object in a real-world scene: foveal vision or extrafoveal vision? This question was assessed in an object search experiment where gaze-contingent display changes created artificial Blindspots and Spotlights. In a 2(+1) × 3 design, the type of image degradation (Blindspots / Spotlights (+Control)) was crossed with three window sizes (radii: 1.6, 2.9, and 4.1 deg). Gaze-centered Blindspots and Spotlights were created on the fly by blending the original colored scene photograph and a low-pass filtered version of it into each other via a spatial Gaussian weight mask. When searching the scene with artificially impaired central vision (Blindspots), search performance was relatively unimpaired, highlighting the importance of extrafoveal scene analysis in search. Artificially impairing extrafoveal scene analysis (Spotlights) affected attentional selection and visual processing; smaller windows led to a reduced likelihood of finding the target, longer search times, and shorter saccades. The 4.1 deg window was identified as the cross-over point of equal search times in Blindspot and Spotlight conditions. However, a gaze-data based decomposition of RTs into search initiation time, scanning time, and verification time [Malcolm & Henderson, 2009, *Journal of Vision*, 9(11), 13] revealed differences in particular sub-processes of search.

Influence of foveal and peripheral spatial frequencies on eye movements during scene inspection and visual search

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Functional segregation of our visual system starts at the retina. Fovea and ventral stream specialize in processing fine detail (high frequencies) for object recognition, and periphery and dorsal stream in processing coarse, low-frequency information for spatial orienting and saccade target selection. Here we study the influence of spatial frequency information on eye movements in scene perception using gaze-contingent filtering. Gaussian-profile high- and low-pass filters were applied to either the fovea or the periphery, and compared to an unchanged control condition. In a scene inspection task (Experiment 1), peripheral and foveal filtering resulted in shortening and lengthening of saccades, respectively; foveal low-pass filtering caused a further increase of long saccades, suggesting that saccades preferentially target regions with unimpaired information. Adaptation of saccade amplitudes was fastest for peripheral low-pass filtering. Fixation durations increased whenever appropriate information was still available (foveal high-pass; peripheral low-pass), but, surprisingly, were unaffected when useful information was attenuated (foveal low-pass; peripheral high-pass). This suggests that saccade programs are inhibited by visual processing difficulty, but that default timing takes precedence when useful information is effectively unavailable. Experiment 2 uses a visual search task, and adds a window size manipulation and $1/f^2$ -noise backgrounds to control for scene semantics.

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Measuring the visual attentional field

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We aimed at developing a method to measure the size of the attentional visual field. We measure the time needed to complete a visual search task (non-masked condition). Then, the same task is repeated with a circular mask presented on the monitor that is centred on gaze position and continually updated with saccades. The mask hides the peripheral visual field maintaining only the central visual field visible. The hypothesis is simple: as long as the size of the attentional field is larger than the size of the visual field left free from the mask, the average time needed to find the target should be longer than the time needed under the non-masked condition. When lesions of the posterior parietal cortex are bilateral, patients with optic ataxia may exhibit clinical visuo-perceptual deficits known as simultanagnosia (inability to perceive two objects at the same time), which disappear quickly. However, infra-clinical visuo-perceptual deficits persist possibly due to shrinkage of the attentional visual field [Michel & Henaff, 2004, *Behavioural Neurology*, 15(1-2), 3-13]. We could infer the size of the attentional field of optic ataxia patients, by matching their performance in the non-masked condition with the control subjects' performance with different mask sizes.

Local Jekyll and global Hyde: The dual identity of face identification

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We introduced a new methodology combining gaze-contingent and hybrid (based on spatial-frequency bands decomposition) techniques to examine whether local or global information subtends face identification. The iHybrid technique simultaneously provides, at each fixation, local information from one face and global information from a second face, ensuring full-spectrum, natural looking stimuli (See movie for an illustration of the fixations dynamic over one trial; the dot represents the fixation location: http://www.psy.gla.ac.uk/~miellet/iHybrid_example.mov). iHybrids revealed the existence of two distinct, equally frequent and equally effective information sampling strategies. The local strategy involves fixations on the eyes and the mouth; the global strategy relies on central fixations of the face. All observers used both strategies, often to recover the same identity in different trials of the same experiment. Supplementary Figures can be seen at http://www.psy.gla.ac.uk/~miellet/supplementary_ECEM2011.pdf for a sketch of the methodology and an illustration of the local and global information use. We conclude that the face system flexibly uses local or global stimulus information to identify faces and examine the implications of our findings for face identification.

Gaze-contingent retinal stabilization techniques: Pitfalls and remedies

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Objectives: (a) To show how gaze-contingent retinal stabilization techniques present some potential problems that might have adverse perceptual and oculomotor consequences. (b) To propose new gaze-contingent rules to solve these problems. Methods: We simulate macular scotomas by continuously displaying a gaze-contingent mask in the center of the visual field. We analyse the relationship between gaze and scotoma locations for different oculo-motor patterns. Results: The two main problems are: (a) a transient blink-induced motion of the scotoma while gaze is static, and (b) the intrusion of post-saccadic slow eye movements. We describe how online analysis of pupil-area, gaze and scotoma locations can solve the problem. Conclusions: Overall, the present work should help design, describe and test the paradigms used to simulate retinopathy with gaze-contingent displays.

Reading V: Emergence of word representations

Order of Acquisition in learning novel nonwords: A laboratory analogue of the AoA effect using eye-movements

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Age-of-acquisition (AoA) effects refer to the general finding that words that are acquired earlier in childhood are processed more quickly and/or accurately than words that are acquired later in life. Demonstrating AoA effects using natural language has proven difficult, as AoA is correlated with others factors, such as frequency, imageability and word length. Recently, there has been a drive to simulate AoA effects in the laboratory [so-called Order-of-Acquisition (OoA) effects] by exposing adults to novel items, some presented early and others later in training. Yet, such studies are often artificial, as participants are usually given explicit and intense training with these novel, sometimes meaningless, items. The present study aimed to simulate OoA effects more naturalistically within an eye-movement paradigm by exposing adults to novel nonwords embedded in meaningful sentences. Despite the absence of explicit training, OoA effects were seen both in an offline memory test and in eye-movement measures. Furthermore, participants who performed above chance in the offline memory task showed earlier effects of OoA in the eye movement record. The methodological and theoretical implications of these findings will be discussed.

Reading spaced Chinese text: There is a benefit

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We examined the effect of word spacing on Chinese readers' learning of new 2-character words (both characters were known but their combination was novel; the meaning of the new word could not be derived from the semantics of the individual characters). We recorded adults' and children's eye movements as they read new words embedded in explanatory sentences (the learning session). In this session, participants were divided into further subgroups - half learned the new words in spaced sentences, and half in unspaced sentences. Another day, participants returned for the test session where the new words were presented in another set of sentences; here, all participants read unspaced text. In the learning session, participants in the spaced group read the new words more quickly than participants in the unspaced group. Further, children in the spaced group maintained this benefit in the test session (unspaced text). In relation to models of Chinese word processing, we argue that the spacing manipulation allowed the children to form either stronger connections between the two characters' representations and the corresponding, novel word representation, or to form a more fully specified representation of the word itself.

Insights into the development of orthographic familiarity through Fixation-Related Potentials: An eye for detail

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The repeated reading of a novel word typically leads to an increased recognition of its written form. This process - which can be called orthographic learning - often occurs while reading paragraphs of text. Most neuroscientific techniques cannot measure brain responses to novel words in paragraphs because it is not clear when a reader is looking at the novel word of interest within a paragraph. To avoid this problem, the current study used an eye-tracker in combination with EEG recordings to measure fixation-related potentials (FRPs) to novel words (pseudonyms) and real words (high frequency names) within paragraphs of text. The novel words and real words were presented four times within each paragraph. The novel words elicited a different pattern of brain activity compared to real words when read for the first time over the left posterior-parietal region. This difference was no longer evident by the fourth exposure. Further, a linear attenuation of early occipital peaks in response to repeated reading of both the real names and pseudonyms was also found. The relationship between orthographic familiarity and attention will be discussed in light of the results, as well as the relationship between eye-movements and electrophysiology.

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Emergence of frequency effects in eye movements

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At two extremes, theories of eye-movement control posit that eye-movements in reading are driven predominantly by a) autonomous saccade generation or b) cognitive factors (e.g., word frequency). A visual search experiment employing strings of Landolt Cs examined how string frequency and difficulty of processing (i.e., gap size of Cs within a string) affected eye-movements. Participants were presented with a line of eight strings at a time and scanned from left to right while searching for a string containing an O. The effects of practice were controlled with blocked presentation of stimuli, counterbalanced across participants. Gap size within a string affected eye movements, with participants looking longer at strings with smaller gap sizes. More critically, as participants' exposures to a given string increased, their gaze duration, total viewing time and number of fixations on that string decreased, independent of practice in the task. The effect of frequency suggests that participants were processing the string holistically and that the difficulty of retrieving information associated with the string from memory affected eye movement behavior. The findings provide evidence for the role of cognition in guiding eye movements and an explanation for the word-frequency effects observed in reading.

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Perceptual specificity effects in re-reading: Evidence from eye movements

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Four experiments examined perceptual specificity effects using a re-reading paradigm. Eye movements were monitored while participants read the same target word twice, in two different low-constraint sentence frames. The congruency of perceptual processing was manipulated by either presenting the target word in the same font (i.e., typography) during the first and second presentations (i.e., the congruent condition), or changing the font of the word across the two presentations (i.e., the incongruent condition). Fixation times for the second presentation of the target word were shorter for the congruent condition compared to the incongruent condition. The magnitude of this congruency effect was larger for low frequency than for high frequency words, and it was larger for more difficult and unusual typographies as compared to less difficult typographies. Furthermore, the congruency effect persisted across a one-week lag between the first and second presentations of the word. Theoretical implications are discussed with a focus on the proceduralist viewpoint (e.g., Kolers, 1976, *Journal of Experimental Psychology: Human Learning & Memory*, 2(5), 554-565). In general, the present demonstration of memory for superficial perceptual details (i.e., typography) supports the existence of perceptually specific memory representations.

The strategic nature of repeated reading benefit: An eye-movement analysis of refutation text processing

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Eye-movement research investigating the repeated reading of an expository text has demonstrated a repetition benefit. However, repetition benefits may be a consequence of increased use of strategic processing rather than a general facilitation effect. In the present study, we examined whether repetition benefits occur when readers' misconceptions concerning the discussed text topic are signalled. Half of the participants read a refutation text in which the text content was introduced by sentences explicitly refusing misconceptions a reader may hold about the phenomenon described in the text, and another half a standard text in which the text content was introduced by neutral sentences. Both texts described a science topic. During rereading the text was identical to that they had read before, only the introduction was deleted. Results showed that the refutation-text readers looked back in the text less during the first reading than the non-refutation text readers, indicating that refutation made initial processing relatively effortless. On the other hand, during rereading, they made more look-backs than the non-refutation text readers, which suggests that refutation increases strategic integrative processing during the second reading. The present study demonstrated repetition benefits to be at least in part strategic in nature, as indexed by look-back fixations.

Symposium - Binocular coordination: Reading, depth and 3D applications

Binocular reading in dyslexic versus normal children

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Binocular coordination of a group of dyslexic children (mean age 11.4 years old) and a group of normal readers of similar age (mean age 11.3 years old) was compared in two tasks of text reading and visual search. Binocular eye movements were recorded by an infrared system (mobileEBT®, e(ye)BRAIN). Preliminary results showed that the amplitude of saccades was lightly larger during reading (4.2° and 4.4° for dyslexics and normal readers, respectively) than during visual search task (3.9° and 3.5°, respectively). Saccade disconjugacy was larger in dyslexics than in normal readers: 1.2° vs 0.4° during reading and 1.2° vs 0.5° during visual search. Important vergence movements during the fixation period were also observed in dyslexics with respect to normal readers: 1.7° vs 0.4° during reading and 1.9° vs 0.5° during visual search. Finally, the duration of fixations was also significantly longer in dyslexic children than in normal readers: 569 ms vs 371 ms during reading and 564 ms vs 362 ms in the visual search task. The atypical eye movement's patterns observed in dyslexic children regardless the task tested suggest a deficiency in the visual attentional processing as well as an immaturity of the oculomotor saccade vergence systems interaction.

Vergence drifts in fixations during reading: Preprogrammed or disparity driven?

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When fixating binocularly whilst reading a unified visual percept during fixation occurs via fusional processes operating over different retinal inputs. Corresponding vergence adjustments, very fundamentally, are supposed to be disparity driven, even though previous reports have suggested that post-saccadic drifts might be due to pre-programmed interactions of saccade and vergence movements [see for example, Heller & Radach, 1999, In Becker et al. (Eds), pp 341-348]. In our first experiment participants read sentences, in which the first half of the words were presented binocularly while the last half of the words were presented to one eye only. We found that as soon as a "fusion lock" was missing (i.e., when there was only a single retinal input), the coordination of the eyes with respect to vergence was "open-loop": relative to observations during binocular fixations, the drift in the unstimulated eye was in the opposite direction and the magnitude of the drift in the "reading" eye increased slightly. The disconjugacy observed during saccades was not affected by the kind of presentation (monocular vs. binocular). We conclude, therefore, that vergence adjustments during binocular fixations in reading appear to be disparity driven. We investigated this observation further by using a saccade contingent change paradigm in a second experiment.

Retinal disparity, size constancy, and reading

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We will outline how binocular disparity in reading and in depth processing in the 3D world can be drawn together in the same theoretical framework. We will describe a haploscopic single-word reading experiment in which participants judged the relative sizes of different words containing the same number of letters, presented above and below an initial fixation point. We show that the size constancy effect, precipitated by binocular disparity, interacts with vertical position in the visual field and with the sex of the participant. We outline some of the implications for visual discrimination in reading in a system that is flexible enough to take advantage of the variability in the visual aspects of the reading task.

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Microsaccadic rate effects during smooth and stepwise depth tracking

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Using stereoscopic displays in two depth-tracking tasks we introduced disparity by a static target dot in one display and an oscillating target dot in the contralateral display. Their visual fusion elicited a stable percept of movement in depth. The first task was to track a smoothly moving target. In the second task the target oscillated between two different depth planes (ϕ movement). Gaze trajectories for both eyes oscillate in phase with the oscillating target, though much weaker in the eye presented with the static target. Binocular microsaccades show a strong coupling of orientation. Monocular microsaccades, however, tend to be oriented ipsilaterally, both for the oscillating and the aligned display. The microsaccade rate and mean orientation show oscillations related to the time course of the presented disparity and can be interpreted as preparatory behavior. The possible role of microsaccades for binocular gaze control will be discussed in depth.

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Improving stereoscopic displays: Why vergence-accommodation conflicts matter and how they might be solved

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Conventional stereoscopic displays present an unnatural stimulus to the visual system. Images are presented on a single focal plane, resulting in a 'conflict' between the blur stimulus to accommodation and the disparity stimulus to vergence. Because these systems are synergistically coupled, this often results in inaccurate vergence and accommodation responses, as well as causing fatigue, poor stereo performance, and distortions in perceived depth. The incorrect stimulus to accommodation can therefore be not only a practical problem in applied settings, but also a confound in experimental studies. A promising solution is to approximate continuous variations in focal distance by distributing image intensity across a number of relatively widely spaced image planes—a technique referred to as depth filtering. We have explored the effectiveness of this technique by measuring vergence and accommodation responses to depth-filtered stimuli, at various simulated distances. Specifically, we determined the maximum image-plane separation that supports accurate vergence and accommodation (i.e. equivalent to responses to real-world stimuli). Accommodation and vergence responses were accurate for image-plane separations of ~0.6-0.9 dioptres. Thus, depth filtering can be used to precisely match accommodation and vergence demand in a practical stereoscopic display, using a relatively small number of image planes.

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Disparity vergence step responses and returns to baseline: Peak velocities and steady state vergence errors

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A crossed disparity step stimulus (relative to a baseline vergence stimulus that has the corresponding accommodative stimulus) induces a forward convergent movement towards the disparity stimulus; when this crossed disparity is removed and the fusion stimulus returns to baseline, the resulting backward movement is divergent. Similarly, uncrossed disparities induce forward divergent and backward convergent movements. We presented crossed and uncrossed disparity step stimuli up to 2 deg in an haploscope with 6 deg baseline vergence and corresponding 60 cm accommodative distance. 25 observers were tested with purpose-made EyeLink II procedures. Backward velocity (towards the depth plane with corresponding accommodative stimulus) was about 30 % higher than forward velocity, on average: individual differences of this effect were related to the accommodative response functions of these observers. After the initial dynamic phase, vergence reached a steady state that typically lagged behind the stimulus. This vergence error represents a fixation disparity relative to the disparity stimulus. The fixation disparity as a function of disparity stimulus (FD-curve) is affected by the discrepancy between accommodative and vergence stimulus (forced vergence). We obtained idiosyncratic objective FD-curves that resembled those known from subjective nonius measurements in optometry, however objective fixation disparities were much larger.

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Perception & Attention

Active visual sampling strategy adapts to environmental uncertainty

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Eye movements serve to gather information from the environment. Multiple sources of information have to be inspected sequentially and each of these sources may be uncertain or noisy. We asked whether the active visual sampling strategy used for picking up information from the environment is adapted to the uncertainty of different information sources. Observers performed relative motion direction discrimination between two random dot kinematograms (RDKs) over a fixed period of time. Motion information delivery was gaze-contingent: a pattern moved only when fixated. Uncertainty is inversely related to the number of coherently moving dots in the patterns. When comparing a low coherence with a high coherence pattern, the total gaze time on the low coherence pattern was longer, but only when the perceptual decision was correct. Prolonged temporal integration of the more noisy pattern may reduce the uncertainty associated with that option. Observers switched more often between RDKs when a high coherence pattern was viewed second. The additional inspection of the information source sampled first may further reduce uncertainty or counteract decay of the memory representation of the first pattern during the second fixation. Overall, observers are able to adapt online to environmental contingencies when required to sample from independent sources.

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Decoupling of pre-saccadic attention performance and saccadic initiation along the vertical meridian

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Visual performance near the vertical meridian is known to be better in the lower visual field (LVF) than the upper visual field (UVF). In contrast, saccades have shorter reaction times to targets in the UVF than LVF. Given that a pre-saccadic attention shift is tightly coupled to saccade execution, and that saccade reaction times might depend on attentional deployment, we tested whether pre-saccadic facilitation would be better and more rapid in the UVF or LVF. Normal subjects made saccades to a figure "8" at 7° of visual angle, either above or below fixation, depending on the orientation of an arrow cue at fixation. At various times (SOA) following the cue presentation, but before the saccade, a target appeared for a short duration (adapted to the subjects performance) at the cued location (on 90% of the trials). After the movement, subjects reported the identity of the target, in a 4-forced-choice response. We also tested the subjects in a condition without saccade (covert attention). We find that targets presented before saccades are identified better even at short SOAs if presented in the LVF than in the UVF, despite the saccades' reaction time being shorter for the UVF.

Saccade preparation and attention-for-perception are dissociated by an onset distractor

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Converging evidence from the last 15 years has shown that saccade control and attention-for-visual-perception are coupled in space and time. "Where-to-look-next?" seems to be controlled by "where-to-attend-next?". Recent single cell studies (e.g., on the frontal eye field) cast doubt on this tight coupling hypothesis. On the basis of a previously published experimental paradigm [Deubel & Schneider, 1996, *Vision Research*, 36, 1827-1837], we created a dissociation scenario by adding an irrelevant onset distractor to the standard saccade and perceptual discrimination task. The results reveal differential spatial effects of the distractor on saccade landing (a "global effect") and on perceptual performance (a position-specific cueing effect). Based on these results, a tentative "two-stages-two-pathways" model on the relationship of attention-for-perception and saccade control will be offered.

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Eye movements and attention during manual grasping

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We investigated the spatial deployment of attention and the eye fixation behavior during manual grasping. Subjects grasped cylindrical objects with thumb and index finger. A perceptual discrimination task was used to assess the distribution of visual attention prior to the execution of the grasping movement. Results showed enhanced discrimination for the locations where index finger and thumb would touch the object, as compared to the action-irrelevant locations. In a separate study, a same-different task was used to confirm that attention was deployed in parallel to both grasp-relevant locations. Taken together, our findings confirm the important role of attention in grasp preparation and provide evidence for divided attention in grasping with two fingers. Interestingly, while attention seems to be split to the action-relevant locations, the eyes tend to fixate the center of the to-be-grasped object, reflecting a dissociation between overt and covert attention.

How magicians use language to misdirect visuospatial attention

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Magic tricks offer powerful tools to manipulate people's attention and conscious experience. Using real-world eyetracking we can investigate how different misdirection cues drive people's eye movements. Moreover, by measuring people's susceptibility to the trick, we can evaluate how these cues influence people's conscious experience. We used a magic trick to explore the way in which spoken questions influence eye movements and perception of an event. The trick involved a fully visible colour change as a probe of whether participants displayed change blindness due to social misdirection. Our results show that the question resulted in 80% of the participants fixating the magicians face. Moreover, even when explicitly instructed not to look at the magician's face, 50% of the participants could not prevent themselves from looking at the face, thus demonstrating that linguistic cues are very powerful in driving attention towards the face. Moreover, 50% of the participants failed to detect the colour change thus illustrating that the misdirection was effective in preventing participants from perceiving a visible change. However, the detection of the change was independent of the instructions, thus suggesting that covert attentional capture by the question was independent of top down control.

Eye-fixation-related potentials reflect encoding failures in change blindness

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Observers are prone to detection failure when, between subsequent presentations of a scene, some of its features are changed. We studied change blindness as resulting from encoding failure of the initial scene, by analyzing eye fixation-related potentials (EFRP) in free viewing conditions. For saccades landing inside the change region, correct change detection ensued when EFRP amplitude corresponded to the extent of the saccade, indicating that the region was given overt attention. In detection failures, EFRP amplitude did not correspond to the extent of the saccade, indicating a covert attentional shift. By contrast, saccade sizes and fixation durations around the target region were not predictive of subsequent change detection. These findings are evidence that overt attention is needed for successful encoding and that dissociation between the direction of eye movements and attention leads to change blindness.

Symposium - Scanpath representation and comparison

A (scan)path to a better memory for pictures? Evidence from scanpath similarity and manipulation

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The concept of an eye movement sequence as an important unit of analysis is bound up in Scanpath Theory [Noton & Stark, 1971, *Vision Research*, 11, 929-942]. This theory predicts that reinstating the same eye movements should help observers recognize a previously seen image. It has since been shown—using several different comparison methods—that the scanpaths of an individual viewing the same scene on two separate occasions are significantly more similar than chance. The eye movements made on two different occasions might be similar for a number of reasons (saliency, meaning, systematic tendencies) but is this similarity causally related to memory across viewings? Current data relating scanpath similarity to memory performance is scarce and correlational. We therefore describe a stronger test of scanpath theory, which constrains the sequence of fixations during the encoding or recognition of natural images in order to manipulate scanpath similarity. In several experiments we find improved memory when the same fixation sequence is re-instated during recognition. Furthermore, our paradigm can test which aspects of similarity—spatial, sequential, iconic—lead to improved performance. In addition to results from improved scanpath comparison methods, these findings have implications for scene perception, memory and embodied cognition.

Picture search is in the eye of the beholder

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There are currently two main methods of pictorial database search: Description Imaging (attaching a textual label) and Content Based Image Retrieval (automatic analysis of low-level features such as colour or texture). This talk discusses a possible third option - Eye Movement controlled image retrieval - involving computer recognition of scanpaths produced whilst imagining an object, based on a variation of the Hough Transformation. The feasibility of the program was explored in several experiments, two of which are discussed. In the first, participants were asked to look at pictures in preparation for a memory test and later imagine those pictures on a blank screen. Scanpaths at encoding and imagery were compared using a String Editing technique and revealed above-chance similarity scores. To increase similarity between scanpaths, the second experiment modified the instructions given to participants, asking them to 'trace' objects with their eyes and later 'draw' these with their eyes, from memory. Although both studies present evidence in favour of an Eye Movement controlled image retrieval system, the string editing technique is critically evaluated and it is suggested that a different scanpath analysis is incorporated to maximise the system's potential.

Consistency of 3D eye movement sequences using ScanMatch during object recognition

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Recordings of eye movements whilst viewing images, videos or even real scenes have been studied for decades but has so far been expressed exclusively in 2D spatial locations (X and Y) and over time (T). Here, using a traditional corneal reflection eye tracker (Eyelink 1000) we used stimuli rendered from 3D mesh objects to compute and map the depth (Z) of collected eye movements. Our goal was to elucidate the role of eye movements while performing object recognition. We extended the ScanMatch method (Cristino et al. 2010, *Behaviour Research Methods*, 42, 692-700) to work with 3D eye movement data (X, Y, Z and T) with the mesh faces used to spatially bin eye movements. Using object meshes to map fixations enables us to fully compare eye movements from different viewpoints. The substitution matrix to weight the ScanMatch sequence substitutions can be expressed as either the Euclidean distance between mesh faces or based upon curvature models of the 3D mesh (convexities and concavities). In an experiment where participants were asked to perform a recognition task on previously learned objects (using anaglyph stimuli) we used ScanMatch to compare 3D eye movement sequences across different viewpoints to study their spatial and temporal consistency.

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Scan pattern dynamics in comprehension and production

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Speakers and listeners engaged in a dialogue establish mutual understanding by coordinating their linguistic and visual responses [Pickering and Garrod, 2007, *Trends in Cognitive Sciences*, 11(3), 105-110 ; Richardson et al., 2007, *Psychological Science*, 18(5), 407-413]. Despite general evidence of coordination, the linguistic and scene factors involved in this coordination are not well understood. In this study, we explore the role of subject animacy and referential ambiguity (the number of competing visual referents) on scan pattern coordination, during the production and comprehension of scene descriptions. Production and comprehension interact differently over time with visual attention. In comprehension, visual responses are launched after the linguistic material is understood, whereas in production, they are launched prior or during speaking. To account for this phenomenon, we use Cross Recurrence Analysis (Dale et al., 2011), which quantifies the temporal variability of time series and captures the underlying patterns of regularity. We find that scan pattern coordination emerges during linguistic processing, and it is especially pronounced for inanimate unambiguous subjects. When the subject is referentially ambiguous, scan pattern variability increases to the extent that the animacy effect is neutralized. Our results suggest that by studying scan pattern dynamics we can unravel the factors that underlie cross-modal interaction in cognition.

Scanpath similarity depends on how you look at it: Evaluating a 'MultiMatch' comparison algorithm

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Visual scanpaths represent a paradox; they are incredibly revealing yet inherently difficult to compare. Here we evaluate our new method for comparing scanpaths [Jarodzka et al., 2010, Proceedings of the 2010 Symposium on Eye-Tracking Research & Applications, 211-218]. Instead of representing fixation-and-saccade sequences by way of discreet Regions of Interest (ROIs) and comparing strings of corresponding letters for similarity (cf. Levenshtein string-edit distance), or representing scanpaths as Gaussian-based attention map functions which retain no information about the order of fixations, our 'MultiMatch' method treats scanpaths as geometric vectors and performs pair-wise comparisons based on a number of dimensions: shape, position, length, direction and duration. This requires a simplification step using thresholding to align scanpaths, and enables us to quantify characteristics which other comparison principles find problematic. With data from two experiments we assess how this algorithm copes with within- and between-subject similarity calculations, how task difficulty affects scanpath similarity, and how the similarity metric produced is dependent on scanpath length. Scanpaths can be similar in a number of intuitive ways, and the capability of our method to use multiple dimensions allows these qualitative distinctions to be tested empirically.

Scanpath comparison with heatmaps

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Scanpaths, generally represented as a sequence of (x,y,t) fixations, express both the spatial position and temporal order of recorded eye movements. Aggregate visualizations of multiple scanpaths tend to become cluttered. The popular heatmap alternative, akin to histogram visualization, displays frequency of attended stimuli with less clutter, sacrificing order information. A sequence/clarity tradeoff exists between the two complementary approaches. Analogously, two general approaches to the comparison of scanpaths have emerged: the first, related to the string-editing approach preserves order information, and the second, based on a similarity metric derived from the heatmap representation, operates on aggregated scanpath sets instead of scanpath pairs. The string-based comparison approach, like its visualization counterpart, is susceptible to a "saturation" effect: given enough scanpaths, eventually both positional (S_p) and directional (S_s) metrics will converge to 1. The heatmap-based method, on the other hand, is meant for aggregate representation, and is immune to this type of saturation. On the other hand, the heatmap-based approach loses temporal order information and, at the moment, its implementation is exceedingly slow (consuming hours to process data collected from 4-minute video clips). The approach is highly parallelizable, however, offering potentially better scalability than the inherently pair-wise string-based alternative.

Tracking Motion

Altered transfer of visual motion information to parietal cortex in psychotic disorders: Implications for visual tracking

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Objective: To identify alterations in neural networks for visual motion perception and pursuit tracking and their interrelationship in schizophrenia, and secondarily to evaluate their comparability to findings in psychotic bipolar disorder. **Design, Setting, and Participants:** Untreated first-episode patients with schizophrenia (N=24) and psychotic bipolar disorder (N=13), and 20 matched healthy participants performed a passive visual motion processing task and a pursuit eye tracking task, which patients have been shown to perform as well as healthy subjects, during functional neuroimaging. Available subjects were retested after four weeks, during which both patient groups received second generation antipsychotics. **Results:** During the motion processing task, neither patient group showed reduced activation in V5, but activations in its projection fields in posterior parietal cortex were reduced in both groups. Pursuit related neural activation in both patients groups was not reduced in sensorimotor systems, but was enhanced in anterior intraparietal sulcus and insula. In schizophrenia, activation was also enhanced in dorsolateral prefrontal cortex and dorsomedial thalamus. **Conclusions:** Greater V5 activation during passive motion processing predicted greater activation in posterior parietal cortex during pursuit in healthy individuals but not in patients. The only significant change at follow-up was decreased anterior cingulate activation during pursuit in schizophrenia.

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Ocular following response for natural-statistic visual stimuli

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Speed is an essential piece of information to control action in a dynamical environment. In order to measure speed and direction of moving objects, the cortical motion system pools information across different spatiotemporal channels. These channels are constituted of populations of speed-tuned neurons in Medio Temporal cortex. The Ocular Following Response (OFR) is driven by speed information extracted by these channels. We analysed human OFR while varying the spatial frequency bandwidth (Bsf) of natural-statistic stimuli for different: speeds, central spatial frequencies and contrasts. We found that a larger Bsf elicits stronger initial eye velocity during the open-loop part of tracking responses, and that this response changes as a function of spatial frequency, contrast and speed. Furthermore we found that with a larger Bsf the response variability decreases and this effect produces a better discrimination between stimuli with very close speeds. We proposed a likelihood model to explain how the visual system pools motion information from the spatiotemporal channels for this oculomotor task.

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Catch-up saccades: Influence on the quality of smooth pursuit

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This research was focused on ocular pursuit of a target (dot), which moved along two-dimensional non-predictable and predictable trajectories with three different average speeds. Due to long tracking (more than 10s), the sequences of successive catch-up saccades were obtained and their parameters were computed. Relationships between the parameters of the sequences of catch-up saccades (amplitude, peak velocity, inter-saccadic interval), driving parameters of catch-up saccades (position error, retinal slip) and parameter of oculo-motor system (pursuit gain) were analyzed. Experimental results indicated that an oculo-motor system was able to react to the instantaneous target velocity and did not use the information about average target speed. Due to large variety of target velocities and shapes of non-predictable and predictable trajectory segments, the parameters of successive catch-up saccades were more scattered compared with the results from previous studies, indicating flexibility of the coordination of quick and slow eye movements. Catch-up saccades reduced eye-position errors by about 30% to 50%; for higher target velocities and predictable trajectories reduction was bigger. The directions of the majority of catch-up saccades were oriented to the target position at the onset of catch-up saccade. Tracking accuracy did not improve by replacing dot target with the segment of target trajectory.

The role of anticipation and prediction in smooth pursuit in Parkinson's disease

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Patients with Parkinson's disease (PD) have difficulties in self-guided (internally driven) movements. The basal ganglia provide a non-specific internal cue for the development of a preparatory activity for a given movement in the sequence of repetitive movements. Controversy surrounds the questions whether PD patients are capable of (a) anticipating own movements before an external trigger appears and (b) continuing a movement even though the target shortly disappears (prediction). We examined internally generated smooth pursuit eye movements in 17 PD patients and 20 age-matched healthy controls by systematically varying extinction periods of a trapezoidally moving target ($16^\circ/s$) in 4 paradigms. The same was examined in a ramp paradigm at gaze straight ahead. These paradigms systematically tested internal (extra-retinal) mechanism in predictable pursuit responses. When compared with controls PD patients showed (i) decreased smooth pursuit gain and acceleration and (ii) reduced anticipatory pursuit. Since we found no attentional deficits PD patients cannot develop sufficient internal drive according to an expected future target motion event whereas predictive mechanisms seem to be preserved or used in a compensatory way to overcome motor problems.

Shared velocity feedback for saccades and smooth pursuit: A control system explanation for eye movement abnormalities

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Spinocerebellar ataxia type 3 (SCA3), also known as Machado Joseph disease, is a rare genetic neurodegenerative disease. Among various eye movement abnormalities, slow saccades and low gain smooth pursuit have been well described in SCA3. Using the scleral search coil system, we found that saccadic overshoots are also frequent in SCA3. Herein, we use models from engineering control systems in order to link those abnormalities. Saccades and smooth pursuit have different functions. While those two systems look distinct, there is evidence that they have shared mechanisms [Liston & Krauzlis, 2003, *J. Neuroscience*, 23:11305; Keller & Missal, 2003, *Ann NY Acad. Sci.*, 1004:29]. Saccades can be viewed as a step input to a control system. In designing a control system there is a trade-off between increasing reaction time and minimizing overshoot. For example, in a second order system, high gain will reduce the response time but will introduce an over-shoot. One technique to overcome this tradeoff is to add a velocity feedback. In the current presentation we will argue that the lack of velocity feedback in SCA3 patients can explain the measured abnormalities in smooth pursuit as well as the slow saccades and frequent overshoots.

Investigation of eye-hand coordination during oculo-manual pursuit and self-moved target guiding along labyrinth path

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In this research human eye-hand coordination during execution of oculo-manual tasks was investigated. In the first set of experiments, oculo-motor and oculo-manual pursuit of the target moving on the computer screen was analyzed. The target which was moving at three different velocities along two-dimensional non-predictive trajectory was pursued by gaze and by hand (cursor). Tracking errors between target and gaze (T-G) and between target and cursor (T-H) were analyzed. T-G and T-H tracking delays were evaluated using an artificial shift in time at which tracking error was minimal. In the second set of experiments, eye-hand coordination was investigated while subjects performed oculo-manual guiding along different complexity labyrinth paths, presented on the screen. Trajectories of the cursor, gaze and difference between them were analyzed and eye-hand coordination strategies were compared with results obtained in the first experiments. In the target pursuit experiments, it was noticed that T-E errors were 45% smaller than T-H errors, nevertheless T-H delays were smaller than T-E delays. This means that target pursuit by hand demonstrates better prediction than pursuit by eye. During the second set of experiments, gaze was always moving ahead of the hand to support the hand control system with information about the path ahead.

Reading & Scenes: Individual differences

Observing interactions: Viewing strategies and autistic traits

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Autistic traits are widely prevalent in the general population. A quantitative estimation of the degree to which an individual possesses traits associated with the autistic spectrum can be assessed using the Autism-spectrum Quotient (AQ). The reported study investigated social attention in 32 adults who either scored very high or very low on the AQ. Participants viewed video clips of four social interactions while their eye movements were tracked. For one of the clips, they were simply asked to watch; for the other three clips, they were asked to make judgements: about how the people were feeling during filming; to recount the events in the clips; or to recall which objects were used in the clips. The resulting effects on participants' eye movements were assessed. Preliminary analyses indicate that the low AQ scorers had a flexible viewing strategy and visually explored the clips much more than the high AQ scorers, who tended to maintain fixation in a more restricted region. Further region of interest analyses and time-course analyses are being conducted. This study informs of the differences in social attention strategies in typically developing adults who display many or very few autistic traits.

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Eye movements reveal no immediate 'Which One's Weird' effect in Autism Spectrum Disorder

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Asperger's Disorder (ASD) and Typically Developed (TD) adult participants viewed pairs of pictures for a simple, spot the difference (STD), and a complex, which one's weird (WOW) task. Eye movement and behavioural measures were similar in both groups for the simple STD task, but differed for the complex WOW task. Here the ASD group took longer to make the decision, longer to begin fixating the target region, and failed to 'pick up' immediately on what was 'weird' when they got to that region. Underconnectivity within and between neural systems at the level of the cortex could underpin observed deficits and the findings are entirely in line with the complex information processing theory of ASD (Minshew & Goldstein, 1998). Importantly, we interpret our data to suggest that characteristic communication deficits observed in ASD may reflect an inability to quickly detect important cues or information that is present in fast moving everyday social environments.

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Language processing and oculomotor control relate to reading deficits in schizophrenia: A moving window reading study

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Skilled reading requires eye movements to bring textual material into foveal view at a self-driven pace. Intact oculomotor control and language are thus necessary to successfully read. Dysfunction of oculomotor control and language processing has long been linked to schizophrenia, schizophrenia spectrum disorders, and the clinically well relatives of people with schizophrenia. While reading is impaired in schizophrenia [Revheim et al., 2006, *Schizophrenia Research*, 87, 238-245], it is unclear whether language or oculomotor dysfunction drives these impairments. To investigate this issue, we tested 18 people with schizophrenia and 10 healthy matched controls using a moving window paradigm, which manipulated parafoveal information to the right of fixation (2, 6, 10, and 14 characters vs. no window). Linear mixed effects analyses showed that people with schizophrenia exhibited reduced perceptual spans for several measures (forward saccade length, reading rate) except first fixation duration. Among patients, forward saccade length (indicative of perceptual span) was associated with phonological awareness (CTOPP) and oculomotor control ability (smooth pursuit, anti-saccades), whereas first fixation duration (indicative of lexical processing) was associated only with language comprehension ability (Nelson-Denny). Thus, language and oculomotor dysfunction both impair reading in schizophrenia, however, their effects are manifested differently in the eye movement record.

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Eye movement evidence for defocused attention in depression - a perceptual span analysis

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The defocused attention hypothesis [von Hecker & Meiser, *Emotion*, 5, 456-463, 2005] assumes that negative mood broadens attention, whereas the analytical rumination hypothesis [Andrews & Thompson, *Psychological Review*, 116, 620-654, 2009] suggests a narrowing of the attentional focus with depression. We tested these conflicting hypotheses by directly measuring the perceptual span in groups of depressed and control subjects, using eye tracking. In the moving window paradigm information outside of a variable-width gaze-contingent window was masked during reading of sentences. In measures of sentence reading time and mean fixation duration, depressed subjects were affected earlier and more strongly than controls by a reduced window size. This difference supports the defocused attention hypothesis and seems hard to reconcile with a narrowing of attentional focus.

Spatial frequency filtering reveals age-related differences in reading

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It is well-established that normal aging produces a progressive decline in sensitivity to spatial frequencies, predominantly in the higher range [for a review, see Owsley, in press, *Vision Research*], but little is known about the influence of this loss of sensitivity on reading performance. We therefore investigated the effects of spatial-frequency information on reading performance of young (18-30 years) and older (65+ years) adults with normal or corrected-to-normal acuity and who showed typical age-related differences in spatial-frequency sensitivity, using a novel moving window paradigm in which areas of text containing only low, medium, or high spatial frequencies were presented around the point of gaze. For young adults, reading performance was modulated by the spatial-frequency content within an area 9 characters wide (the perceptual region), and reading was disrupted most when this perceptual region contained only low spatial frequencies. In contrast, the perceptual region for older adults was more than 15 characters wide, and reading was disrupted most when this perceptual region contained only high spatial frequencies. These findings indicate that older adults use the spatial-frequency content of text from a wider area than that used by young adults and rely more than young adults on coarse-scale information for reading.

Binocular eye-movements of dyslexic readers: Prioritising the abducting eye and purposeful movements within a fixation

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We present details of the largest database of binocular eye-movements in reading by UK dyslexic university students, reading 5000 words of multi-line text and using monocular calibration. We profile their performance on a range of cognitive and linguistic tasks, and present initial analyses of their eye-movements compared with those of more typical readers of the same corpus. We describe participants' binocular behaviours within a fixation, asking how readers solve the problem of making the two eyes (with their mirror-image musculatures) move optimally. As an example of our analyses, 85% and 82% of non-dyslexic and dyslexic participants, respectively, converged in front of the plane of the text; we explored these fixations according to spatial direction of movement of each eye within the fixation. Within individual fixations both eyes moved to the right, with the right (abducting) eye behaving similarly for both reading groups. However, dyslexics' left eye movements showed a more variable profile, making a significant proportion of movements to the left. Such analyses do not specifically identify visuomotor causes of dyslexia; rather, they describe the results of dyslexic readers optimising their available resources, both visuomotor and cognitive.

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