Journal of Eye Movement Research
5(5):4, 1-8

Heterophoria: Vergence stability and visual acuity after asymmetric saccades

Bernhard M. Blum
German Dizziness Center (IFB)
Ludwig-Maximilians University Munich

Daniel Kirchhoff
Department of Neurology
Ludwig-Maximilians University Munich

Alexander Bickmann
Department of Ophthalmology
Ludwig-Maximilians University Munich

Oliver Ehrt
German Dizziness Center (IFB) and
Department of Ophthalmology
Ludwig-Maximilians University Munich

Andreas Straube
German Dizziness Center (IFB) and
Department of Neurology
Ludwig-Maximilians University Munich

Thomas Eggert
German Dizziness Center (IFB) and
Department of Neurology
Ludwig-Maximilians University Munich

Many patients with heterophoria report on symptoms related to impaired vision. To investigate whether these symptoms are provoked by saccades this study examines whether in heterophoria effects on intrasaccadic and postsaccadic vergence movements are linked to effects on visual performance. Visual acuity was measured in 35 healthy subjects during fixation and immediately after asymmetric diverging saccades. Binocular position traces were recorded by video-oculography. Subjects with exophoria showed larger intrasaccadic divergence amplitudes, which in turn led to smaller postsaccadic divergence amplitudes. Visual acuity did not depend on heterophoria or vergence amplitudes. The results suggest that compensating for exophoria requires increased convergence activity as compared to orthophoria or compensated esophoria. Visual acuity seemed relatively robust with respect to postsaccadic vergence movements.

Keywords: heterophoria, vergence, asymmetric saccades, visual acuity

Introduction

Heterophoria is a tendency for the eyes to misalign when they are dissociated, such as when one eye is covered (von Noorden & Campos, 2002). The distribution of absolute heterophoria in a symptom-free otherwise randomly selected population has a median of 0.3 deg with quartiles at 0.1 and 0.6 deg both for esophoria and for exophoria (Dowley, 1990). Even with phoria angles inside this range, temporary decompensation of the heterophoria resulting in loss of fusion and visual impairments can occur (Gall & Wick, 2003). In these cases vergence and accommodative facilities are believed to play an important role (Gall & Wick, 2003). Vergence disorders are known to interfere with dynamic oculomotor parameters like saccade and vergence latencies (Bucci, Kapoula, Yang, & Brmond-Gignac, 2006) and with reading performance (Stein, Richardson, & Fowler, 2000). Lack of vergence stability during fixation, especially immediately after saccades can also be expected in heterophoria. This is because saccade-vergence interaction is believed to play an essential role in controlling intrasaccadic vergence (Zee, Fitzgibbon, & Optican, 1992). From that perspective, using vergence signals to compensate for heterophoria could result in modified and possibly inappropriate intrasaccadic vergence that in turn would also induce postsaccadic vergence movements. This hypothesis can be made for saccades to isovergent targets or to targets in depth. Postsaccadic vergence movements could be related to a deficit in postsaccadic fusion. It is not known

Author notes: Parts of the results were presented at the 16th European Conference on Eye Movements (ECEM 2011) in Marseille, France, August 2011.

Acknowledgements: This project was supported by funds from the German Federal Ministry of Education and Research under the grant code 01 EO 0901. The authors bear full responsibility for the content of this publication.

Contact information: Bernhard M. Blum, German Dizziness Center (IFB), University Hospital Munich, Campus Grosshadern, Marchioninistr. 15, 81377 Munich, Email: bernhard.blum@med.uni-muenchen.de

DOI 10.16910/jemr.5.5.4

ISSN 1995-8692

whether visual impairments in heterophores are provoked by postsaccadic vergence instability.

To address this question the current study measures visual acuity and vergence movements in orthophoric and heterophoric subjects during fixation and immediately after asymmetrical diverging saccades.

Method

Subjects

Thirty-five healthy subjects (twenty-one female and twenty-one male) were included in the study. Their ages ranged from 16 to 72 years (M = 39 years, SD = 16 years). They had no history of strabismus or eye muscle surgery and their binocular vision was normal or corrected-to-normal with astigmatism lower or equal to 0.5 diopters. No limits of phoria angle were imposed for the inclusion of subjects. All subjects had normal stereopsis as assessed by the Lang 1 Stereotest (Brown, Weih, Mukesh, McCarty, & Taylor, 2001). During the experiment subjects could wear their contact lenses or were fitted with the spherical equivalent of their habitual refractive correction using a single-lens holder on the EyeSeeCam video-oculography system (see next paragraph). All subjects gave their written informed consent. The study protocol was approved by the Ethics Committee of the Medical Faculty of the LMU.

Eye Movement Recording

Asymmetrical horizontal saccades from both eyes were recorded simultaneously with the EyeSeeCam that provides video-oculography (VOG) combined with a realtime experimentation system (Dera, Böning, Bardins, & Schneider, 2006). The calibration was done for each eye individually under monocular far viewing of a head-fixed laser pattern. Subjects fixated a central and four peripheral laser dots at 8.5 degrees eccentricity on the horizontal and vertical meridians. The procedure was identical to that applied by Ladda, Eggert, Glasauer, and Straube (2007) and Eggert, Ladda, and Straube (2009) and achieved an absolute position accuracy of 0.5 – 1 deg. Eye position signals were sampled at 220 Hz.

Experimental Setup

In a dark room, subjects were seated with their heads stabilized by a chin rest in front of a monitor centered in the subjects sagittal plane (shown in Figure 1). Two lateral fixation LEDs were presented at a viewing distance of 0.5 m and at a gaze eccentricity of 10 degrees to the left or to the right. The central saccade target was presented on the monitor at a viewing distance of 3.6 m. With an interpupillary distance of 0.065 m a saccade from one lateral near LED (vergence angle: 7.22 deg) to the far central target (vergence angle: 1.03 deg) had a divergence requirement of -6.17 deg.

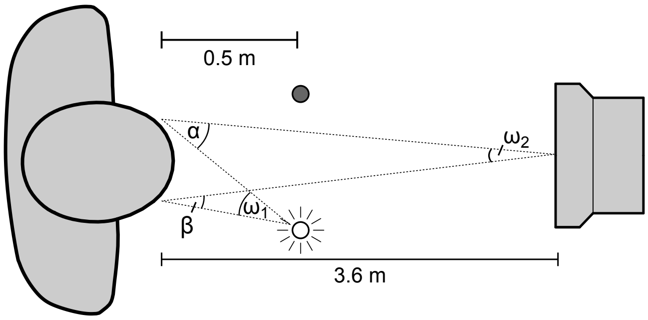

Figure 1. View of the experimental setup from above. The subject performed an asymmetrical saccade (version change = $(\alpha + \beta) / 2$) with a divergence requirement $\omega_1 - \omega_2$ of -6.17 deg from one of two near LEDs (0.5 m distance, 10 deg left or right) to a far target centered on the monitor (3.6 m distance).

Measurements

One experiment comprised three consecutive measurements with oculomotor and perceptual discrimination tasks. After the subjects had been given instructions and a short training session with all three tasks, the three measurements were recorded in the order as listed below. The measurements followed each other with breaks of less than one minute between measurements.

Phoria Measurement. An objective measurement of phoria angle was established by the eye movement recordings during an alternate cover test. Subjects fixated a static cross (height x width: 10 x 10 arc min; line width: 1 arc min) at 3.6 m viewing distance while the examiner alternately covered each of the subjects eyes for 1.5 seconds (von Noorden & Campos, 2002; Schmidt et al., 2004). The test comprised 28 trials and lasted 42 s.

Visual Acuity. Two different measurements of visual acuity were performed using a flashed Landolt-C displayed on the central monitor: one during static fixation (fixation test) and another after asymmetrical saccades (saccade test). The difference between these two measures quantifies how much visual acuity is impaired after saccades. The perceptual task was the same for both. A visual target in the form of a ring was presented at the center of the monitor. The luminous sterance of the ring was about 30 cd/m and that of the dark background was below 1 cd/m. In a forced choice task subjects had to indicate the direction of a gap that pseudo-randomly opened at one of four oblique positions in the closed ring for a period of 100 ms, transforming the ring into a Landolt-C. The procedure is based on that of Baron and Westheimer (1973). Subjects indicated the perceived orientation of the Landolt-C by moving the computer mouse in one of four alternative directions. The diameter of the ring was initially set

DOI 10.16910/jemr.5.5.4

ISSN 1995-8692

in such a way that the corresponding Landolt-C had a gap of 1 arc min. From trial to trial the size was adaptively adjusted by a Bayesian adaptive psychometric procedure that approximated the proportion of correct responses to 85%. We used the MATLAB implementation of this so-called QUEST procedure (Watson & Pelli, 1983) by Pelli and Brainard (2004).

In the fixation test visual acuity was estimated while subjects fixated the ring. The test comprised 40 trials and lasted for about 3 minutes. In the saccade test subjects performed asymmetrical (divergent) saccades between one of the lateral nearby LED targets and the central far distant ring target. The target was the same closed ring as in the fixation test. Subjects were instructed to make a saccade to the closed ring immediately after its appearance on the otherwise dark screen. The start position (on the left or the right LED) was chosen in a pseudo-random order. As in the fixation test, the ring was temporarily replaced by a Landolt-C for 100 ms. The opening of the gap was triggered immediately after saccade end as detected by an online processing of the VOG signal. Again subjects responded by moving the mouse. The ring disappeared after the mouse response. The test comprised 40 trials for each saccade direction (left/right) and lasted about 8 minutes.

Data Analysis

Exclusion Criteria. In total 58 subjects participated in the study. Twenty-three of these subjects had to be excluded for various reasons. First, in the saccade test, the quality of the visual acuity measure depends mainly on the number of trials in which the target ring is in the vicinity of the fovea at the moment at which the gap appears. This was frequently not the case, since we triggered the gap by the end of the first saccade after the go-signal (i.e. the appearance of the closed ring). Invalid trials in which subjects either anticipated the go-signal, or in which they approached the target by two or more staircase saccades had to be excluded from the analysis. Sixteen subjects who performed fewer than 30 valid trials per saccade direction were also excluded from the study. On average, across the included subjects, 95% of the trials were valid. Second, in the fixation test (baseline) some remaining subjects seemed to have very bad acuity, possibly because they had problems attending the stimulus at the time of gap appearance. Seven subjects whose baseline visual acuity threshold was considered as outlier according to the standard criterion as defined by Velleman and Hoaglin (2004, p. 67–69) were excluded from further analysis.

Saccade Detection. Saccade start and end were detected by standard velocity criteria as described in previous studies (Eggert, Mezger, Robinson, & Straube, 1999; Eggert, Sailer, Ditterich, & Straube, 2002). Only movements with durations between 10 and 100 ms and with peak velocities below 800 deg/s were accepted. In the alternate cover test the peak velocity of a movement had to be larger than 10 deg/s in order to be accepted as a saccade. These limits were chosen because the velocity and duration of normal saccades with amplitudes below 30 deg are known to stay within these limits (Becker, 1989; Engbert & Kliegl, 2003).

Phoria Angle. Barnard and Thomson (1995) showed that, after disruption of binocular vision, ocular vergence stabilizes only after 5 to 10 s. Therefore the first 12 seconds (8 trials) of the alternate cover test were discarded. The remaining 20 trials were used to estimate the phoria angle as follows. Accurate refixation saccades after switching the occlusion between the two eyes have the amplitude of the misalignment during occlusion. For example, in exophoria, if the eyes are in a divergent position during occlusion of the right eye, upon uncovering of this eye refixation saccades should be directed to the left and vice versa. The direction of the refixation saccades was standardized so that it always appeared leftward in exophoria and rightward in esophoria. This was achieved by reversing the direction of refixation saccades that occurred after uncovering of the left eye (see Figure 2). For each subject the phoria angle was then calculated as the mean amplitude of refixating saccades in the version trace (mean of left and right eye position). If no version saccades could be detected in more than two thirds of the cover test trials, the phoria angle was considered to be 0 deg. This method of determining the phoria angle is not affected by offset errors of the calibration, as the mean vergence angle (left eye right eye position) would be. The within-subject standard error (SE) of the amplitude of the refixation saccade is reported as a measure of accuracy for this method.

Vergence Amplitudes. The mean intrasaccadic vergence amplitude was defined by the vergence change between start and end of the saccade from the near lateral LED to the far central target, averaged across saccades. The postsaccadic vergence amplitude was defined as the slow vergence drift from saccade end to the end of the presentation of the Landolt-C. Since in the saccade test both intrasaccadic and postsaccadic vergence movements were divergent for all subjects, only the absolute values of vergence amplitudes are reported for the sake of simplicity.

Visual Acuity. The 85% threshold of the Landolt-C gap width, as estimated by the QUEST routine and expressed in units of arc min, was used as a measure of visual performance. Hereafter we call this measure visual acuity threshold even though it differs from the standard (Snellen) acuity measure. The QUEST procedure also provides an estimate of the standard error of the log threshold which indicates the accuracy of the measure. To compare visual acuity between groups the base-10 logarithm of the acuity threshold (logThresh) was used because it was normally distributed in

DOI 10.16910/jemr.5.5.4

ISSN 1995-8692

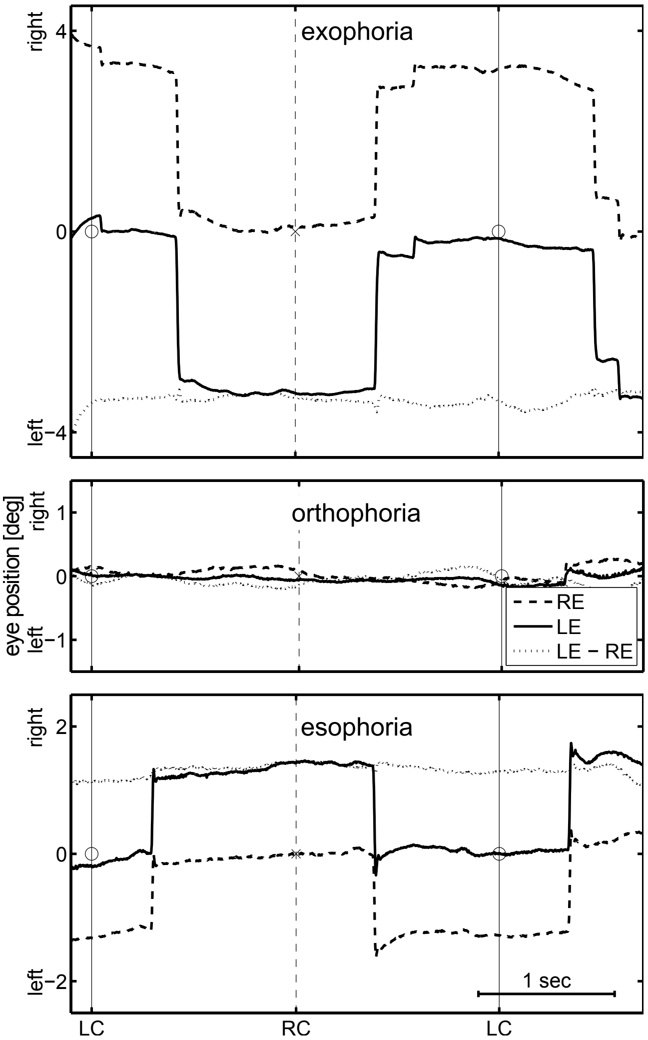

Figure 2. Phoria types. Left eye (LE; solid line) and right eye (RE; dashed line) position and vergence (LE - RE; dotted line) during three exemplary trials during the alternate cover test for each type of exophoria (top), orthophoria (center), and esophoria (bottom). Vertical lines indicate the beginning of the occlusion of the left eye (LC) or the right eye (RC). Traces start during the late occlusion of the right eye while the left eye is on target (0 deg). In exophoria the subject makes a leftward or rightward saccade after covering at LC or at RC, respectively. The orthophoric subject makes no saccades.

our subject group (Lilliefors $p > 0.11$). Because the visual acuity threshold after leftward saccades did not significantly differ from those after rightward saccades (paired T-test on logThresh: $t(34) = -0.07$, $p = 0.95$), only the average across both saccade directions is reported here.

Statistics. Group mean and between-subjects standard deviation (N = 35) are reported for normally distributed variables whereas median; [first quartile, third quartile] are reported for non-normally distributed variables. Normality was tested with the Lilliefors test. To assess the dependence between the different measures, Spearmans correlation coefficient (rank-correlation) was used because it is robust with respect to deviations from normality. Effects in statistical hypothesis tests were considered significant with alpha-error probabilities of $p < 0.05$.

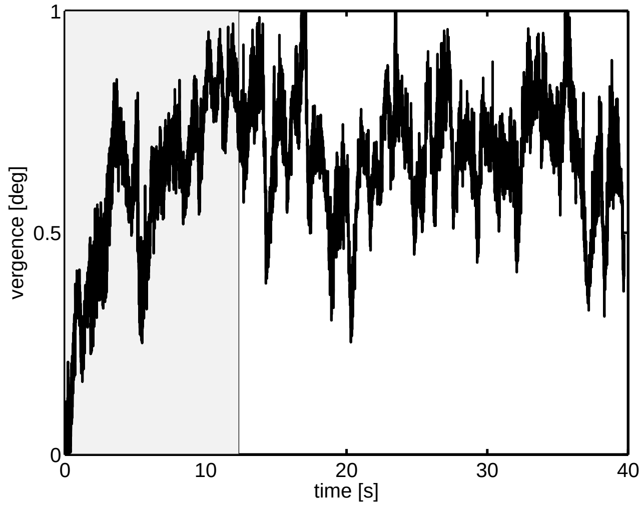

Figure 3. Time course of the vergence angle during the alternate cover test in a single exophoric subject. The vergence trace (solid) shows the difference between left and right eye position. The initial gray shaded area indicates the 12 second period excluded from the analysis.

Results

Phoria Angles

Figure 3 shows a typical example of an alternate cover test recording in a single esophoric subject (phoria angle: 0.68 deg). In this example, as with the majority of subjects, the absolute vergence angle was quite stable during the last 20 trials used to estimate the phoria angle (see Methods). The median of the phoria angles across subjects (Table 1) did not significantly differ from zero (Wilcoxon signed rank test: $p = 0.22$). The phoria angles were not normally distributed across the population (Lilliefors $p < 0.001$), due to negative skewness indicating a longer tail for exophoria than for esophoria.

Intrasaccadic Vergence Amplitudes

In the saccade test, the group mean of the absolute intrasaccadic vergence amplitude (1.46 deg, Table 1) was much smaller than required (6.17 deg). Figure 4 shows that the absolute intrasaccadic vergence amplitude of the subjects correlated negatively with their phoria angle (Table 2, line 1). The negative correlation indicates that subjects with more exophoria (negative)

DOI 10.16910/jemr.5.5.4

ISSN 1995-8692

Table 1
Group Statistics For Each Measure.

Measures	Group statistics (N = 35)	
	Mean/median	Median of within-subject SE
Phoria angle	0.25; [-0.34, 0.67] deg	0.04 deg
Absolute intrasaccadic vergence amplitude	1.46 ± 0.69 deg	0.05 deg
Absolute postsaccadic vergence amplitude	2.75 ± 1.06 deg	0.06 deg
Visual acuity during fixation	2.34; [2.05, 2.88] arc min	0.04 $\log_{10}$(deg)
Visual acuity after saccades	10.28; [7.14, 12.98] arc min	0.05 $\log_{10}$(deg)

Note: The first column shows the descriptive statistics of the measures. Mean ± standard deviation are given for normally distributed measures. Median; [first quartile, third quartile] are given for non-normally distributed measures. The second column shows the group median of within-subject standard error. These values provide an estimate of the accuracy of the individual measure for a single subject.

Table 2
Spearmans Correlation Coefficients (r) Between Pairs of Measures.

Measures		Spearmans correlation coefficient (N = 35)	
Var1	Var2	r	p
Absolute intrasaccadic vergence amplitude	Phoria angle	**-0.40**	**0.02**
	Absolute postsaccadic vergence amplitude	**-0.43**	**0.01**
Visual Acuity Threshold	Phoria angle	-0.05	0.77
	Absolute postsaccadic vergence amplitude	-0.27	0.11

Note: Significant correlations (bold typeset) occurred among some of the oculomotor parameters but not between visual acuity and phoria angle or visual acuity and the postsaccadic vergence amplitude.

showed larger absolute intrasaccadic vergence amplitude (positive).

Postsaccadic Vergence Amplitudes

The mean absolute postsaccadic vergence amplitude (2.75 deg, Table 1) indicates that vergence movements continued during the presentation of the Landolt-C. Figure 5 shows the relationship between intrasaccadic and postsaccadic vergence amplitudes for each subject. The two variables showed a significant negative correlation (Table 2, line 2), indicating that subjects with larger intrasaccadic vergence amplitudes performed smaller postsaccadic vergence amplitudes. The coefficient of correlation between postsaccadic vergence amplitudes and phoria angle did not differ significantly from zero (r = -0.06; p = 0.75; N = 35).

Visual Acuity

Figure 6 shows the visual acuity of all 35 analyzed subjects during the fixation test and the saccade test. The group mean of the visual acuity threshold during fixation was smaller than that after saccades (Table 1, lines 4, 5). This difference was significant (paired T-test on logThresh: $t(34) = 21.10$, $p < 0.001$) and showed the same sign in each subject. Table 2 shows that postsaccadic visual acuity did not correlate significantly with either the phoria angle, or the postsaccadic vergence amplitudes.

DOI 10.16910/jemr.5.5.4

ISSN 1995-8692

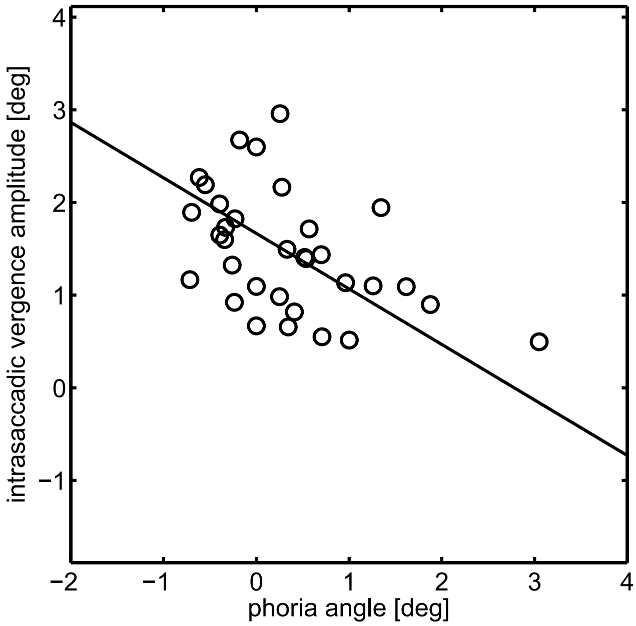

Figure 4. Absolute intrasaccadic vergence amplitudes plotted versus phoria angles. Each symbol represents the mean of a single subject. The line is that minimizing the orthogonal distance to the symbols.

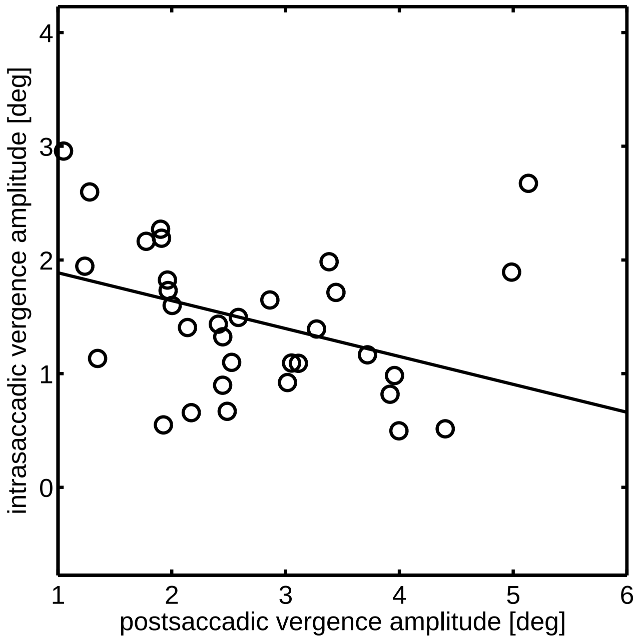

Figure 5. Absolute intrasaccadic vergence amplitudes plotted versus postsaccadic vergence amplitude. Each symbol represents the mean of a single subject.

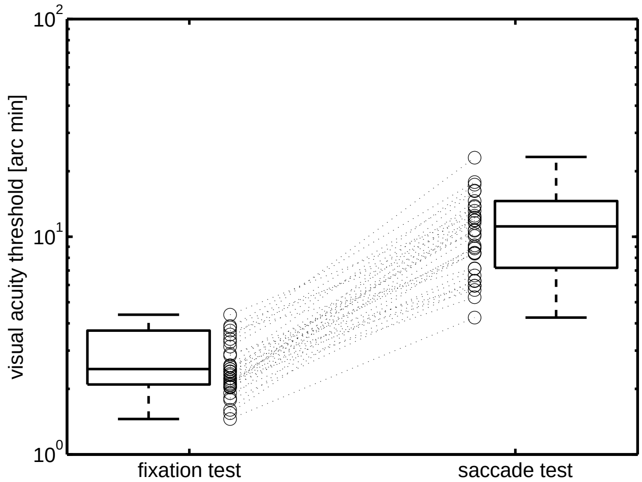

Figure 6. Visual acuity (Landolt-gap size corresponding to 85% correct responses) in the fixation test and the saccade test. Horizontal lines, boxes, and whiskers show the median, the quartiles, and the extremes, respectively. The dotted lines show that in each subject the threshold was smaller during the fixation test than in the saccade test.

Discussion

In the alternate cover test subjects phoria angles could be determined with a median precision of 0.04 deg (SE). This accuracy is about 10 times higher than the absolute accuracy of standard calibration routines of head-mounted VOG systems. These calibrations are limited by the normal fixation accuracy and potential head movements. The accuracy achieved by using the EyeSeeCam VOG system is also much higher than that of the standard alternate cover test as applied in clinical examination. The latter is limited by the minimum amplitude of refixating saccades that the examiner can detect with the unaided eye. Depending on the conditions of illumination during the test, this amplitude varies between 2 and 4 prism diopters (1.15 - 2.29 deg) (Ludvigh, 1949; Romano & von Noorden, 1971). Similar to previous studies (Palomo Alvarez, Puell, Snchez-Ramos, & Villena, 2006) the current study did not show prevalence of exophoria or esophoria in a random sample across the population. Even though our dataset was not normally distributed, the exact difference of the phoria distribution from normal has to be tested in a larger sample.

Phoria angle and intrasaccadic vergence amplitudes were negatively correlated (Fig. 4). This finding might be related to the vergence effort needed in exophoria for binocular fixation of the target. Assuming that fixating the near target required more convergence effort in exophoria than in esophoria would be consistent with the observed larger intrasaccadic divergence amplitudes in exophoria due to a larger vergence release compared to esophoria. Thus, in line with the initial

DOI 10.16910/jemr.5.5.4

ISSN 1995-8692

hypothesis, the negative observed correlation suggests that increased convergence activity is used to compensate for exophoria. The negative correlation between intrasaccadic and postsaccadic vergence amplitudes is expected since vergence amplitudes are positively correlated with vergence requirement. Large intrasaccadic divergence led to a smaller postsaccadic vergence requirement and therefore to smaller postsaccadic vergence. The clear increase of the visual discrimination threshold after saccades compared to fixation does not seem to be related to known mechanisms of saccadic suppression. For example, contrast sensitivity was observed to recover quickly from its drop during the saccade, reaching normal level as early as 50 ms after the saccade end (Diamond, Ross, & Morrone, 2000). For a review see (Ross, Morrone, Goldberg, & Burr, 2001). The effect observed here may instead be due to a direct effect of the large retinal velocities during the saccade that lead to a loss in contrast sensitivity at high frequencies (Burr & Ross, 1982). Temporal integration in early visual processing stages might be responsible for the reduced visual performance shortly after high retinal velocities.

On average the postsaccadic vergence amplitude during the presentation of the Landolt-C was 2.75 deg resulting in a mean disconjugate retinal slip velocity of 2.75/0.1 = 27.5 deg/s. Conjugate retinal velocities of this size are known to impair visual acuity (Westheimer & McKee, 1975; Barmack, 1970) and also contrast sensitivity (Flipse, van der Wildt, Rodenburg, Keemink, & Knol, 1988). Therefore, postsaccadic vergence amplitudes may be expected to impair visual acuity. Contrary to this expectation, postsaccadic vergence amplitudes and visual acuity did not significantly correlate. This could be due to independent noise in the individual estimates of these two parameters because such noise decreases the apparent correlation compared to the true correlation of the noise-free values. However, the reported noise estimates of the postsaccadic vergence amplitude (0.06 deg) and of the log-threshold (0.05 log10(deg)) were so small that the probability of Spearmans correlation coefficient being smaller than the observed $r = 0.27$ was less than 0.001. This was computed by means of a Monte-Carlo simulation assuming that the postsaccadic vergence amplitude and the visual acuity (logThresh) result from a linear relation ($r = 1$) contaminated by noise. This suggests that, in our experiment, postsaccadic vergence was not crucial for postsaccadic visual acuity.

In summary, in a population with minor compensated heterophoria the between-subject differences in visual discrimination may be mainly induced by differences in absolute fixation accuracy, visual (not necessarily binocular) processing, general inconsistency in forced choice response tasks, or other factors that are not directly related to postsaccadic vergence movements. Direct comparison between monocular and binocular viewing conditions seems to be interesting for future research in order to investigate the role of binocular processing for post-saccadic visual acuity in more detail.

References

Barmack, N. H. (1970). Dynamic visual acuity as an index of eye movement control. *Vision Research*, *10*(12), 1377–1391.

Barnard, N. A., & Thomson, W. D. (1995). A quantitative analysis of eye movements during the cover test – a preliminary report. *Ophthalmic & Physiological Optics: The Journal of the British College of Ophthalmic Opticians (Optometrists)*, *15*(5), 413–419.

Baron, W. S., & Westheimer, G. (1973). Visual acuity as a function of exposure duration. *Journal of the Optical Society of America*, *63*(2), 212-219.

Becker, W. (1989). Metrics. In Wurtz & Goldberg (Eds.), *The neurobiology of saccadic eye movements* (p. 13-67). Elsevier Science Publishers BV (Biomedical Division).

Brown, S., Weih, L., Mukesh, N., McCarty, C., & Taylor, H. (2001). Assessment of adult stereopsis using the Lang 1 stereotest: A pilot study. *Binocular Vision and Strabismus Quarterly*, *16*(2), 91–98.

Bucci, M. P., Kapoula, Z., Yang, Q., & Brmond-Gignac, D. (2006). Latency of saccades, vergence, and combined movements in children with early onset convergent or divergent strabismus. *Vision Research*, *46*(8-9), 1384–1392.

Burr, D. C., & Ross, J. (1982). Contrast sensitivity at high velocities. *Vision Research*, *22*(4), 479–484.

Dera, T., Böning, G., Bardins, S., & Schneider, E. (2006). Low-latency video tracking of horizontal, vertical, and torsional eye movements as a basis for 3dof realtime motion control of a head-mounted camera. In *Proceedings of the IEEE Conference on Systems, Man, and Cybernetics* (pp. 5191–5196). Taipei, Taiwan.

Diamond, M. R., Ross, J., & Morrone, M. C. (2000). Extraretinal control of saccadic suppression. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *20*(9), 3449–3455.

Dowley, D. (1990). Heterophoria. *Optometry and Vision Science: Official Publication of the American Academy of Optometry*, *67*(6), 456–460.

Eggert, T., Ladda, J., & Straube, A. (2009). Inferring the future target trajectory from visual context: Is visual background structure used for anticipatory smooth pursuit? *Experimental Brain Research*, *196*(2), 205–215.

Eggert, T., Mezger, F., Robinson, F., & Straube, A. (1999). Orbital position dependency is different for the gain of externally and internally triggered saccades. *Neuroreport*, *10*(12), 2665–2670.

Eggert, T., Sailer, U., Ditterich, J., & Straube, A. (2002). Differential effect of a distractor on primary saccades and perceptual localization. *Vision Research*, *42*(28), 2969–2984.

Engbert, R., & Kliegl, R. (2003). Microsaccades uncover the orientation of covert attention. *Vision Research*, *43*(9), 1035–1045.

Flipse, J. P., van der Wildt, G. J., Rodenburg, M., Keemink, C. J., & Knol, P. G. (1988). Contrast sensitivity for oscillating sine wave gratings during ocular fixation and pursuit. *Vision Research*, *28*(7), 819–826.

Gall, R., & Wick, B. (2003). The symptomatic patient with normal phorias at distance and near: What tests detect a binocular vision problem? *Optometry*, *74*(5), 309-322.

DOI 10.16910/jemr.5.5.4

ISSN 1995-8692

Ladda, J., Eggert, T., Glasauer, S., & Straube, A. (2007). Velocity scaling of cue-induced smooth pursuit acceleration obeys constraints of natural motion. *Experimental Brain Research*, *182*(3), 343–356.

Ludvigh, E. (1949). Amount of eye movement objectively perceptible to the unaided eye. *American Journal of Ophthalmology*, *32*(5), 649.

Palomo Alvarez, C., Puell, M. C., Snchez-Ramos, C., & Villena, C. (2006). Normal values of distance heterophoria and fusional vergence ranges and effects of age. *Graefe's Archive for Clinical and Experimental Ophthalmology*, *244*(7), 821–824.

Pelli, D., & Brainard, D. (2004). *Quest.* http://psych.nyu.edu/pelli/software.html#quest.

Romano, P. E., & von Noorden, G. K. (1971). Limitations of cover test in detecting strabismus. *American Journal of Ophthalmology*, *72*(1), 10–12.

Ross, J., Morrone, M. C., Goldberg, M. E., & Burr, D. C. (2001). Changes in visual perception at the time of saccades. *Trends in Neurosciences*, *24*(2), 113–121.

Schmidt, P., Maguire, M., Dobson, V., Quinn, G., Ciner, E., Cyert, L., … Vision in Preschoolers Study Group (2004). Comparison of preschool vision screening tests as administered by licensed eye care professionals in the vision in preschoolers study. *Ophthalmology*, *111*(4), 637–650.

Stein, J. F., Richardson, A. J., & Fowler, M. S. (2000). Monocular occlusion can improve binocular control and reading in dyslexics. *Brain*, *123*(1), 164–170.

Velleman, P. F., & Hoaglin, D. C. (2004). *Applications, basics, and computing of exploratory data analysis*. The Internet-First University Press.

von Noorden, G. K., & Campos, E. C. (2002). *Binocular vision and ocular motility* (6th ed.; R. Lampert, Ed.). St. Louis, Missouri: Mosby, Inc.

Watson, A. B., & Pelli, D. G. (1983). QUEST: A Bayesian adaptive psychometric method. *Perception & Psychophysics*, *33*(2), 113–120.

Westheimer, G., & McKee, S. P. (1975). Visual acuity in the presence of retinal-image motion. *Journal of the Optical Society of America*, *65*(7), 847–850.

Zee, D. S., Fitzgibbon, E. J., & Optican, L. M. (1992). Saccade-vergence interactions in humans. *Journal of Neurophysiology*, *68*(5), 1624–1641.

DOI 10.16910/jemr.5.5.4

ISSN 1995-8692