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Eye Tracking in Optometry: A Systematic Review

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This systematic review examines the use of eye-tracking devices in optometry, describing their main characteristics, areas of application and metrics used. Using the PRISMA method, a systematic search was performed of three databases. The search strategy identified 141 reports relevant to this topic, indicating the exponential growth over the past ten years of the use of eye trackers in optometry. Eye-tracking technology was applied in at least 12 areas of the field of optometry and rehabilitation, the main ones being optometric device technology, and the assessment, treatment, and analysis of ocular disorders. The main devices reported on were infrared light-based and had an image capture frequency of 60 Hz to 2000 Hz. The main metrics mentioned were fixations, saccadic movements, smooth pursuit, microsaccades, and pupil variables. Study quality was sometimes limited in that incomplete information was provided regarding the devices used, the study design, the methods used, participants' visual function and statistical treatment of data. While there is still a need for more research in this area, eye-tracking devices should be more actively incorporated as a useful tool with both clinical and research applications. This review highlights the robustness this technology offers to obtain objective information about a person's vision in terms of optometry and visual function, with implications for improving visual health services and our understanding of the vision process.

Keywords: Eye-tracking, vision sciences, eye movements, visual technology, optometry, opthalmology

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Introduction

Eye-tracking technology was first introduced in the 19th century and was mainly used to analyze reading processes in people. Other applications described have been its use in clinical neuropsychology and in controlling computers through gaze (Holmqvist & Anderson, 2017; Pluzyczka, 2018).

Recent advances in eye-tracking technology have had an impact in the field of health, including optometry. Today's commercial devices have little to do with their predecessors, and the present is known as the third era of eye trackers with a greater capacity to record and process data (Holmqvist & Anderson, 2017).

Eye trackers consist of a system with a sensor to detect, measure, and capture eye movements and eye positions. Individual eye movements and what the individual is looking at are tracked through different mechanisms such as using an artificial infrared light source that generates a reflection on the cornea, tracking pupil position, and appearance-based eye tracking. Other hardware systems, such as webcams and smartphones, have also been used (Punde et al., 2017; TobiiPro, 2015; Valliappan et al., 2020). These devices also work with special software to process the data and interpret the information obtained.

A multitude of techniques exists to record eye movements, including mirror reflection systems, electrooculogram systems, photoelectric and video-based limbus tracking, sclera coils, canthus and corneal bulge tracking, tracking retinal features, dual Purkinje imaging, dark and bright pupil tracking, pupil and corneal reflection, laser-based pupil and iris tracking, video-based tracking of artificial markers, and the most common method, pupil center corneal reflection (Holmqvist & Anderson, 2017). These techniques are employed by devices such as screen-based eye trackers or wearable eye trackers to collect information.

Eye tracking devices enable the monitoring and recording of eye movements, providing valuable information that can be extracted as raw data samples, including pupil size, pupil position, corneal reflections, fixation and saccade velocities and accelerations, gaze vectors for each eye, and gaze points. Other metrics, such as fixations, saccades, post-saccadic oscillation, smooth pursuit, microsaccades, tremor, and drifts, can be derived from these gaze-related event metrics (Duchowski, 2007; Engbert & Kliegl, 2003; Holmqvist & Anderson, 2017; König & Buffalo, 2014; Punde et al., 2017; Salvucci & Goldberg, 2000; Schweitzer & Rolfs, 2020; Zemblys et al., 2019).

Eye-tracking metrics can facilitate the acquisition of relevant information regarding various aspects of human behavior. Accordingly, eye trackers are used in cognitive psychology, to analyze human-computer interactions, and in marketing, psycholinguistics, neurolinguistics, and sports science, among others (Holmqvist & Anderson, 2017; Romano & Schall, 2014). The basis for these applications is that eye movements provide different levels of information, including gaze properties, eye properties, perception properties, characteristics of cognitive processes, and even opinions and ideas about people's reasoning and clinical aspects of different pathologies (Adams et al., 2017; Al-Haddad et al., 2019; Economides et al., 2021).

The data obtained from these systems can be used for vision assessment, as they offer precise information and metrics on ocular behavior. Eye-tracking technology is also employed in vision analysis instruments that have frequent applications in ophthalmology. Examples are eye trackers associated with optical coherence tomography (OCT), scanning laser ophthalmoscopy and microperimetry.

While eye trackers provide excellent data on certain eye movements, they are highly sophisticated and can be cumbersome to transport (Rahn & Kozak, 2021) limiting the possibilities of modifying the stimuli received or analysis conducted in real-world contexts. In addition, as occurs with the microperimeter, they only allow for monocular tests. As in most individuals the eyes move congruently, a monocular analysis may not offer a comprehensive understanding of human behavior in real-life situations, such as under conditions of low vision.

To circumvent this limitation, new eye tracker devices have been developed for clinical optometry applications. Among these instruments, we should mention screen-based devices and special glasses designed to facilitate manipulation of the stimulus received, the adaptation of tasks, and the selection of eye movements to analyze. These characteristics of eye trackers expand their possibilities to include adjusting instrument calibration or the presentation of stimuli to analyze visual function in specific populations such as children or persons with low vision.

The use of this technology also requires being aware of factors enabling the collection of high-quality data. These include the device's characteristics, sampling rate, accuracy average, the eye-tracking mechanism, and eye-tracking setups or methods of testing. In addition, the importance of calibration, control of head movements, and the characteristics of the environment, such as lighting, temperature and noise, must be considered.

This is why it is important to examine how, up until now, this technology has been used in optometry. Moreover, given that eye trackers have reached a new level of technological readiness, it needs to be established whether these devices and their optometric applications are ready for use in clinical practice.

So far, several review studies have examined the evolution of eye-tracking technology. In 2017, one such review examined the use of microperimetry to assess visual function in age-related macular degeneration. The authors of this study highlighted the benefits of incorporating an eye-tracker in a microperimetry system to correct the position of the stimulus for changes in fixation (Cassels et al., 2018).

In 2020, another study addressed the use of eye tracking in ophthalmology, indicating that this technology is used in modern imaging instruments for patient assessment and imaging diagnostics. This technology also seems to have applications in ophthalmic and refractive surgery (Rahn & Kozak, 2021). However, literature reports of optometry research in general have not discussed the use of this technology in depth, although it has been much used in clinical practice.

Methods

Design

This systematic review was designed to assess the benefits of eye tracking in the field of optometry. We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to describe the information collected and registered our study protocol with PROSPERO (registration number 364762). The flow of the PRISMA search is detailed in Fig. 1. RevMan software (version 5.4, Cochrane, UK) was used to record information.

Search Strategy

The search was conducted in January 2022 and rechecked in July 2022. Titles, abstracts, and bodies of texts were searched in the databases Scopus, Web of Science, and PubMed using the descriptors: ((eye track**) AND (visual acuity)) AND (eye movements) AND (assessment) NOT ((drugs) NOT (psychology). Visual acuity was included as visual function is usually related to visual acuity. This descriptor also helped restrict our search to studies relevant to optometry.

Study Selection

The following inclusion and exclusion criteria were consistently applied throughout the process: 1) papers published between 2017 and 2022 were included to obtain the most recent information; 2) titles and abstracts related to the field of vision; 3) studies conducted in humans; 4) studies using eye-tracking devices as part of their methodology; 5) papers published in English; and 5) conference papers and journal articles. The review excluded editorials, reviews, studies on animals and reports on cognitive function or psychology-related topics.

Inclusion criteria were applied and each title and abstract was screened by two independent reviewers. When a title or abstract provided insufficient information, the reviewers discussed and made decisions to resolve any disagreement. This served to avoid the risk of missing important information and potentially eligible articles.

Data Extraction and Quality Assessment

The reviewers independently reviewed full texts and extracted important data in a collection form. The data extracted for each study were year of publication, main objective, subjects, device characteristics, and metrics/paradigms used. As the review sought to identify the areas of optometry in which eye-tracking systems are used, the parameters extracted could vary from one study to another.

Study quality was assessed based on the following criteria: number of participants, method implemented, reporting of the characteristics of the eye tracker used, and the way in which it was employed.

Statistical Analysis

Given the nature of this systematic review and the lack of quantitative data provided by many of the studies included, the results of our review are presented in narrative form.

Results

In the search and selection process, 1340 reports were identified, of which 714 remained after removing duplicates. Next, the selected articles were screened according to their publication date, language, title, and abstract, leaving 181 candidate reports. Six papers were excluded because they used animals in the studies. The remaining 175 full-text articles were assessed for eligibility, leaving only 141 reports after discarding 34 as they did not exactly relate to the topic.

The initial database search yielded 1340 reports on the use of eye trackers in the field of vision since 1968 (Fig.2). In the past ten years, studies related to the use of eye tracking devices in optometry have undergone an exponential increase, averaging at around 17 articles per year. The year 2018 stands out from the rest as there were 24 scientific publications on the topic.

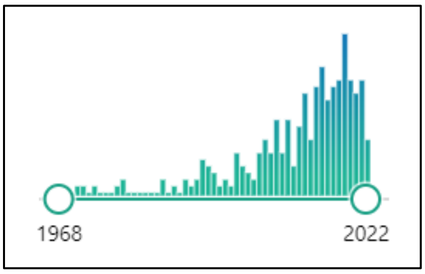

Figure 1. PubMed diagram of publications about eye trackers in vision science by year.

Eye Trackers in the Field of Optometry

After an exhaustive review of all 141 selected reports, these were grouped by area of application in the field of optometry as described below. In Table 2, the information is organized by area of application, main metrics, devices used, benefits of eye tracking, and methodological aspects.

Nystagmus

Nystagmus is an involuntary oscillatory movement of the eyes that can affect a person's visual acuity (Rosengren et al., 2020a). This disorder was analyzed by eye tracking in four of the articles reviewed here. Different types of nystagmus were examined such as voluntary flutter during ophthalmoscopy (Norouzifard et al., 2020; Thomas et al., 2022) or optokinetic nystagmus (Norouzifard et al., 2020). Some authors highlighted the capacity of eye-tracking devices to adequately assess individuals with this condition (Rosengren et al., 2020a).

Visual Acuity

Six of the articles reviewed described studies in which visual acuity was examined as the ability to see details using eye-tracking devices. Four of the studies conducted an analysis of dynamic visual acuity (Ağaoğlu et al., 2018; Chen & Yeh, 2019; Domdei et al., 2021; Palidis et al., 2017) while two investigations focused on behavior, visual control, and detection of targets in situations of reduced visual acuity (Freedman et al., 2018, 2019).

Visual Field

Eye-tracking devices are also used in visual field exams. Nine publications were found on this topic describing studies in which eye movements were used to grade visual health (Mooney et al., 2021) and classify visual field loss (Grillini et al., 2018; Murray et al., 2018). The authors of these studies also explored how vision and eye movements function in a monocular or binocular way when there is central visual field involvement. In individuals with hemianopia, the use of these devices to determine the preferential retinal locus was described in subjects with a macular disorder (Barraza-Bernal et al., 2017a; Barraza-Bernal et al., 2017b; Murray et al., 2018; Shanidze et al., 2017; Woutersen et al., 2020).

Amblyopia/Strabismus/Vergences

Seven of the articles reviewed addressed amblyopia, strabismus and vergences. In one study, anomalies in monocular and binocular motility were analyzed in children with amblyopia (Murray et al., 2022). Eye-tracker devices were also used as a resource to detect strabismus, mainly characterizing skills for fixation stability (Al-Haddad et al., 2019; Kelly et al., 2019a; Zrinscak et al., 2021) and visual searching (Aizenman & Levi, 2021; Satgunam et al., 2021; Tsirlin et al., 2018).

Three of the studies reviewed focused on the topic of exotropia as one of the most common types of strabismus. In these studies, the factors considered were exophoria, intermittent exotropia (Adams et al., 2017; Economides et al., 2021), and longitudinal changes in slow visual searches in subjects with this type of exotropia undergoing surgery (Mihara et al., 2020). Ocular incompatibility and dominance were also addressed by some authors (Adams et al., 2017).

Nine of the studies identified the use of eye-tracking devices to analyze visual functions. These included characteristics such as convergence, divergence, accommodation, and stereopsis. Eye movement data were collected when taking measurements at the near-point of convergence or vergence (Feil et al., 2017; Kim et al., 2022; Namaeh et al., 2020; Ramakrishnan & Stevenson, 2020). Some studies even used technology to perform automated measurements of phorias and heterophorias and determine the influence of age on adaptation to disparity (Alvarez et al., 2017; Gantz & Caspi, 2020; Mestre et al., 2017, 2018, 2021).

Surgery

Three articles examined ocular motility in relation to surgery: one study after strabismus surgery (Perrin-Fievez et al., 2018), another assessed the use of eye trackers in small-incision lenticule extraction (SMILE) procedures (Reinstein et al., 2018), and finally, Coletta and colleagues examined the impact on eye motility of refractive surgery (Coletta et al., 2018).

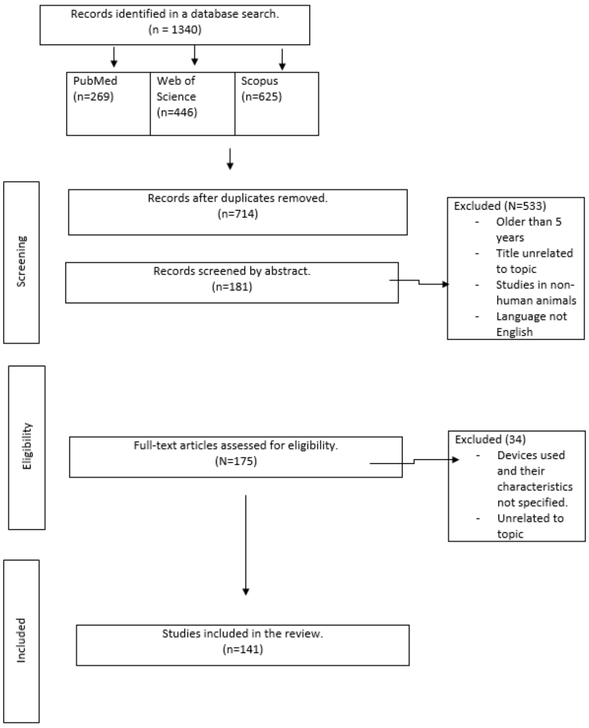

Figure 2. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart.

Technology/Visual Equipment/Virtual and Augmented Reality

Some technological devices, such as video games and virtual and augmented reality systems, incorporate gaze-tracking systems that enable the capture of gaze data. Our review found 18 articles addressing topics related to hardware or software used to improve techniques such as calibration methods, foveated rendering, or the use of portable devices (Albert et al., 2017; Cheong et al., 2018; Esfahlani et al., 2019; Fujimoto et al., 2022; Jones et al., 2019; Kim et al., 2019; Love et al., 2021; Pundlik et al., 2019; Rosengren et al., 2020b). These studies highlight a need for more robust eye trackers for use in different instruments including OCT and microperimetry devices (Chopra et al., 2017; Essig et al., 2021; Hirasawa et al., 2018; Hirota et al., 2021; Lauermann et al., 2017; Mao et al., 2021; Murray et al., 2017).

Ocular Pathology/Low Vision

Nineteen publications documenting the study of ocular disorders were found. The main diseases examined with eye-tracking technology were glaucoma, Stardgart's disease, age-related macular degeneration, diabetic macular edema, and sequellae of concussion. These investigations characterized and examined in detail oculomotor aspects, fixation stability and binocular fixation (Abadia et al., 2017; Asfaw et al., 2018; Ballae Ganeshrao et al., 2021; Barsingerhorn et al., 2019; Gao & Sabel, 2017; Garric et al., 2021; Giacomelli et al., 2020; Jakobsen et al., 2017; Kooiker et al., 2019; Laude et al., 2018; Lee et al., 2017; Senger et al., 2020; Shivdasani et al., 2017; Tarita-Nistor et al., 2017; Titchener et al., 2020). Aspects related to visuospatial orientation and visual comfort were also analyzed (Ballae Ganeshrao et al., 2021; Garric et al., 2021; Kooiker et al., 2019; Leonard et al., 2021). One study was designed to explore how binocular eye movements behave in the presence of scotoma in terms of binocular vision and contrast sensitivity in peripheral vision (Alberti & Bex, 2017). Other authors used an eye tracker to analyze the eye movements of drivers diagnosed with glaucoma (Lee et al., 2019).

Assessment/Diagnosis/Rehabilitation/Training

Most eye-tracking research effort was found centering on the assessment, diagnosis, and treatment of various ocular conditions. We therefore selected 24 articles describing the use of ocular motility parameters for such purposes. In these studies, eye-tracking devices were employed to assess color vision (Taore et al., 2022), contrast sensitivity (Tatiyosyan et al., 2020), and visual function (Wilhelmsen et al., 2021). Ocular motility was used as a biomarker of visual function beyond visual acuity (Brodsky & Good, 2021; Liston et al., 2017; Liu et al., 2017), to develop simple tests to assess slow-to-see behavior in children (Weaterton et al., 2020), to evaluate attention in children with high-visual acuity (Ramesh et al., 2020), and to analyze visual comfort and visual acuity changes in terms of microsaccades (Shelchkova et al., 2019). Eye tracking has also been used to assess non-pathological aspects of eye disorders such as visual fatigue (Mooney et al., 2018; Ryu & Wallraven, 2018; Schönbach et al., 2017; Tatiyosyan et al., 2020; Wang et al., 2020; Wen et al., 2018; Xie et al., 2021), and to identify the preferred retinal locus when there is scotoma in persons with macular degeneration (Yow et al., 2017, 2018). These publications also report on the use of eye trackers to restore visual capacity, and to train visual fields and visual searching(Awada et al., 2022; Axelsson et al., 2019; Chatard et al., 2019; Hotta et al., 2019; Mooney et al., 2021; Perperidis et al., 2021; Tatiyosyan et al., 2020; Wan et al., 2020).

Refractive Error

Two of the studies reviewed examined ocular motility according to refractive error (Doustkouhi et al., 2020; Ohlendorf et al., 2022).

Reading in Optometry Assessment

Nine of the reports reviewed analyzed patterns of ocular motility during reading in both healthy subjects and in those with conditions such as nystagmus (Fadzil et al., 2019) or delayed reading (Vinuela-Navarro et al., 2017). These studies were conducted mainly in children or individuals with visual field loss (Ridder et al., 2017). Stimuli used were short, long, and dynamic texts, and blue light filters (Ryu & Wallraven, 2017). Some authors also compared rapid serial visual presentation and horizontal scrolling text (Bowman et al., 2021; Hyona et al., 2020; Murata et al., 2017; Perrin-Fievez et al., 2018). In other studies, only the benefits of the use of eye trackers during reading were explored (Wertli et al., 2020).

Sports Vision/Locomotion

Another vision field that has been growing in recent years is sports vision, but only one article dealing with this topic was identified. The authors of this report analyzed changes produced in visuomotor behavior in children during training in combat sports (Ju et al., 2018).

Oculomotor Deficits/Oculomotor Responses

Two of the articles reviewed focused on oculomotor responses. One study addressed oculomotor behavior in response to changes at the vestibular level, and the other study was designed to compare oculomotor deficits in adopted and non-adopted children from an unspecified region of Europe (Pueyo et al., 2020; Wibble et al., 2020).

General Eye Movements

Finally, twenty-one of the articles included in our review examined ocular motility in general without focusing on any given population. While these reports cannot be assigned to any of the previous sections, their findings have contributed to the field of optometry. Some of the studies described were designed to determine how much time one needs to fixate during different tasks (Belyaev et al., 2020; Bowers et al., 2021; Chaudhary et al., 2020; Ivanchenko et al., 2019; Kelly et al., 2019b; Ratnam et al., 2018; Seemiller et al., 2018), whether fixation stability leads to reduced head movements in people with Argus II (Caspi et al., 2018), or whether this stability differs between central and peripheral vision (Raveendran et al., 2020).

These studies also analyzed metrics related to different aspects of saccades, such as saccadic rhythmicity (Amit et al., 2017; Poletti et al., 2020; Sheynikhovich et al., 2018), presaccadic motion (Kwon et al., 2019), patterns of saccades (Badler et al., 2019), characteristics of small saccades and microsaccades (Fang et al., 2018; Nanjappa & McPeek, 2021), dynamic perisaccades (Intoy et al., 2021), smooth pursuit (Goettker et al., 2019; González et al., 2019), and visual perception (Pel et al., 2019; Vater et al., 2017). Some articles highlighted data on disparity and deviations between the eyes and different positions of gaze (Barraza-Bernal, Rifai et al., 2017a, 2017b; P. Liu et al., 2021; Namaeh et al., 2020; Ramakrishnan & Stevenson, 2020; Wibble et al., 2020).

Methods Used

Main Devices and Their Characteristics.

Eye tracking devices use different methods of collecting information on eye positions. In most of the studies reviewed, this was pupillary corneal reflection. In Appendix 1, the devices used by area of application are listed. Four eye tracker brands emerged as most used in the field of optometry: Eyelink 1000 (SR Research, Ontario, Canada) (n=37), those of the company Tobii (TobiiTechnology, Stockholm, Sweden) (n=36), Dual Purkinje eye tracker (Fourward Technologies) (n=5), and the SMI eye tracker (SensoMotoric Instruments GmbH, Teltow, 95 Germany) (n=7).

Some of the eye trackers are incorporated in other technological systems used for vision assessment such as microperimeters (n=2) and tracking scanning laser ophthalmoscopes (n=3). Across all references, these devices have an imaging capture frequency between 60 Hz and 2000 Hz, and are based on the infrared light technique. Both head-mounted and screen-based devices have been employed, depending on whether the exam setting is real-world or controlled environment, respectively.

Table 2. Most commonly used eye-tracker systems.

Eye-tracker	Features	Price
-Eyelink 1000 (SR Research, Mississauga, Ontario, Canada)  (SR-Research, n.d.)	- Video-based eye tracker. High speed camera. - Sample rate: head free (1000 Hz) or head fixed (2000 Hz). Average accuracy of 0.5 degrees. - Binocular eye tracker - Real time data access. Easy to transport. - Multiple mounting options - Integration possible with EEG, FMRI, MEG, EcoG. - Software: PC-HOST, but compatible with others such as Psychopy, E-Prime. - https://www.sr-research.com/wp-content/uploads/2017/11/eyelink-1000-plus-specifications.pdf	More than 20, 000 USD
- Tobii Products (TobiiTechnology, Stockholm, Sweden) 1. Tobii Glasses 1 mobile head-mounted eye tracker 2. Tobii EyeX 3. Tobii TX300 eye tracker 4. Tobii 4c eye tracker   (Tobii AB, n.d.)	- Sample rate: 30 to 250 Hz - Accuracy: 0.3 degrees - Head-mounted or screen-based devices. - 3D eye model for high calibration gaze data. - Binocular eye tracker. - Data sample output: timestamp, gaze origin, gaze point, pupil diameter - Controlled and natural environments. - Software: Tobii Pro Lab, but compatible with others such as Psychopy, E-Prime. - Some trackers specialized for gaming	From 3,000 USD to 33,000 USD
- SMI eye tracker (SensoMotoric Instruments GmbH, Teltow, 95 Germany)	- Sample rate:60 Hz /120 Hz - Accuracy: 0.5 degrees - Eye-tracking technique: dark pupil - https://imotions.com/products/hardware/smi-eye-tracking-glasses/	Discontinued. Approx. 11,900 USD
-Dual Purkinje Eye tracker (Fourward Technologies	- Sample rate: approx. 500 Hz - Noise level: 20-sec of arcs rms - Eye tracking mechanism: infrared light, positions of the first and fourth Purkinje images	- Dependent on device

Stimuli Setups and Recordings

Owing to the diversity of study populations and objectives, stimulus setups varied widely in terms of color, size, and shape. Setups ranged from a simple black fixation point in primary gaze position or in different positions on the screen, to smooth pursuit stimuli and cartoon videos for pediatric populations (Cheong et al., 2018; Pueyo et al., 2020; Vinuela-Navarro et al., 2017), images of real-life situations (Albert et al., 2017), or standardized tests assessing reading or ocular motility (Ridder et al., 2017; Taore et al., 2022; Woutersen et al., 2020). Some stationary and dynamic stimuli were created by the researchers mainly using programs like Matlab and Python.

Each experiment started with some calibration procedure. These ranged from using two dots in two different positions, to as many as nine dots. Only a few research groups reported on the accuracy considered acceptable for calibration (1º of accuracy) (Adams et al., 2017; Economides et al., 2021).

Additionally, the distance between the individual and stimulus varied from 20 cm to 6 m, the average distance in most experiments being 55 cm. For each experiment or trial, durations varied as they depended on the individual's reaction.

Main Metrics Used and Statistical Analysis

According to the data obtained, the main metrics used in the studies as a source of information were those related to fixations (n=60), saccadic movements (n=41), eye position (n=25), smooth pursuit (n=13), and microsaccades (n=10). For each motility measure, the factors analyzed were number and total average, total time, average time, frequency, amplitude of motion, total time in activity, and reaction time. On occasion, data were analyzed both monocularly and binocularly.

Event-related measures were mainly used to locate any important event (metrics) while recording the timeline. In this process, eye movements were first recorded and then metrics were analyzed. In a few reports, algorithms were implemented to obtain quantitative data. The most used procedure was the bivariate contour ellipse area (BCEA) method, which served to calculate fixation stability.

Only some reports indicated the type of research conducted: prospective experimental cohort study (Garric et al., 2021), comparative study (Tatham et al., 2020), prospective study (Wan et al., 2020), longitudinal study (Kooiker et al., 2019), cross-sectional studies (Hirasawa et al., 2018; Jakobsen et al., 2017; Laude et al., 2018; Murata et al., 2017; Murray et al., 2022), and case-control study (Gao & Sabel, 2017). Twenty-seven of the articles reported having established a control group with which to compare data from subjects with eye disease.

In general, the articles mentioned several modes of statistical data treatment. Most reports provided descriptive statistics (mean, median, standard deviation, interquartile range), and described the use of comparison and correlation tests on their datasets, and dependent and non-dependent groups for parametric and nonparametric data (Appendix 1).

Discussion

According to our database search, eye-tracking devices have been used for scientific research in the field of optometry since 1968. The year 2018 stands out as the year in which there was the largest number of publications related to this topic. Within the field of optometry, the use of these devices has been described in at least 12 different areas.

Our comparison of the different studies identified and reviewed was hindered by the diversity of data handled, mainly because of the different populations, eye-tracking devices, and metrics involved.

Main Areas of Application

Among the main application areas of eye trackers (optometry device technology, and assessment, treatment, and analysis of eye conditions), our review revealed the diagnosis and treatment of different eye conditions as a constant interest in optometry. Consistently, in recent years, eye-tracking technology has been used to improve vision assessment, expand vision care services, for example, to include applications of eye trackers in telemedicine, and even allow for the early detection or and/or prevention of certain eye conditions (di Stefano, 2002). For these purposes, eye-tracking programs are useful tools as they can be easily integrated into commonly used technologies such as tablets, cell phones, and computers (Jones, 2020; Jones et al., 2019).

Devices Used and Their Characteristics

The most common characteristic of the eye-tracking devices employed in the studies reviewed were infrared light technology, involving a capture frequency greater than 60 Hz, although most exceeded 125 Hz (Holmqvist & Anderson, 2017). The characteristic features of the four most commonly used devices are compared in Table 2. Devices marketed by Tobii and Eyelink seem to be the preferred systems yet their availability in some institutions is somewhat limited by their high cost.

The mechanism of action of most devices reported on was the corneal reflex technique. However, some research groups used eye trackers based on pupil-corneal reflection to obtain more static measurements, such as fixations, as this technique is considered ineffective to study the dynamics of eye movements or dynamic saccadic movements (Hooge et al., 2016; SR-Research Eye Link).

Most eye trackers were screen-based devices. These allow for a more controlled environment, the presentation of specific stimuli on screen, and even the incorporation of a chinrest, which is recommended to control head movements (Ju et al., 2018; Thomas et al., 2022).

Some studies reported on the use of head-mounted trackers. Such devices are useful for taking measurements in different environments and even during persons' daily activities or real-life situations (Abadi et al., 2021; Chaudhary et al., 2020; Chow-Wing-Bom et al., 2020; Freedman et al., 2019; Fujimoto et al., 2022).

It should be mentioned that almost all the reviewed studies used experimental setups such that the devices used were not designed as optometric diagnostic systems. This meant that extensive individual analysis of each person may not have been possible. Currently, only especially manufactured optometric devices have wide applications in clinics.

Main Metrics Used

Many of the studies reviewed were designed to analyze fixations, saccadic movements, smooth pursuit, microsaccades, and pupil variables, as the typical ocular movements used to generate metrics (Holmqvist & Anderson, 2017). Most reported data were obtained by segmenting the experiment into distinct tasks or events. This allowed for an improved analysis of ocular behavior at specific moments and made it possible to assess the total number of fixations or saccades produced and their durations and amplitudes, visual search patterns, smooth pursuit, and reaction time.

Methods and Statistical Aspects

After analyzing certain methodological aspects, we found that only 10 articles provided information on the type of study conducted. Most studies were cross-sectional and designed to examine the prevalence and diagnosis of patient conditions such as nystagmus, low vision, and strabismus, among others. In most reports, the sample size estimation method used was unclear, and an arbitrary size was mentioned (Chaudhary et al., 2020). Only one group reported on the use of Cochran's formula (Fadzil et al., 2019).

Subject population ages varied from children to adults, revealing the wide applicability of eye trackers. As these are automatic capture devices for which participation or active response of the subject is not always required, they can be employed to assess behavior and visual function in newborn children (Kelly et al., 2019; Perperidis et al., 2021) or older adults (Cheong et al., 2018; Chopra et al., 2017; Gonzalez et al., 2019; Lauermann et al., 2017; Lee et al., 2017, 2019; Liu et al., 2017; Shanidze et al., 2017; Sheynikhovich et al., 2018; Yow et al., 2018).

In some papers, the specific use of the metrics collected or even the eye-tracking paradigm applied were not specified. It is important to study a specific phenomenon and design the experiment properly (Holmqvist & Anderson, 2017). Only nine studies indicated in their methodology the eye-tracking paradigm addressed (Al-Haddad et al., 2019; Badler et al., 2019; Ballae Ganeshrao et al., 2021; Barsingerhorn et al., 2019; Kooiker et al., 2019; Pel et al., 2019; Ramesh et al., 2020; Vater et al., 2017; Wen et al., 2018), especially those assessing eye movements in general, in which the goal was to analyze ocular behavior.

Unlike other studies where eye trackers serve to learn about emotional or cognitive aspects, optometry studies may mainly involve the use raw eye movement data. Many of the studies reviewed, however, had limitations in reporting quality (quality information, statistical power, calibration accuracy, and data loss, among others). Moreover, some did not clearly specify design characteristics and environmental factors (such as device model, frequency of image capture, position, illumination, and temperature). Only one article mentioned having done a pilot study (Pel et al., 2019), as is usually recommended for eye-tracking studies.

Most articles centered on ocular pathologies and low vision reported a large volume of data on visual function. In addition, authors mentioned calibration changes made to ensure subjects could see the stimulus presented. This is important as in this specific area of optometry, extensive subject characterization in terms of visual acuity, contrast sensitivity, or visual field is needed because eye movements can be affected by these factors (Blignaut et al., 2019). Other factors that may need to be specified depending on the main study objectives are pupil size, the number and duration of fixations, saccadic movements and regressions, and eye video, as well as the type of stimulus used, its size and color, the conditions of the space and screen features (Thomson, 2017).

With regard to the statistical treatment of the data obtained, besides providing descriptive statistics such as means, medians, and standard deviations, non-parametric tests were mainly used (Mann-Whitney U, Wilcoxon test, Kruskal Wallis test, Friedman test) as most studies were based on non-representative samples. Three articles patently explained the limitations of eye trackers in their studies, such as calibration problems (Doustkouhi et al., 2020; Mooney et al., 2021), reflection from the surface of lenses (Doustkouhi et al., 2020), the use of glasses, and sample size (Wertli et al., 2020).

Further, although the quality of the evidence provided varied between articles, fourteen studies directly analyzed the usefulness of eye trackers and offered relevant data regarding the validity of their clinical application. Some authors also emphasized the effectiveness and potential of eye trackers, especially for the identification and rehabilitation of patients with ocular disorders, specifically those with visual field loss, through the use of gaze data (Laude et al., 2018; H. Liu et al., 2017; Ratnam et al., 2018; Yow et al., 2018).

Our review identified a need to continue promoting research in this area and to replicate studies with sufficient methodological weight to extrapolate results to the general population.

Technological Readiness

Technology Readiness Level (TRL) is a systematic method designed to grade the maturity level of a given technology. It consists of nine levels:

TRL 1: Basic principles observed
TRL 2: Technology concept formulated
TRL 3: Experimental proof of concept
TRL 4: Technology validated in the laboratory
TRL 5: Validated in a relevant environment
TRL 6: Technology demonstrated in a relevant environment
TRL 7: System prototype demonstration in an operational environment
TRL 8: System completed and qualified
TRL 9: System proven in operational environment (Mankins, 1995).

Many of the devices employed in the studies reviewed, such as those manufactured by Tobii® and Eyelink®, are already marketed and employed in different contexts, including real-life scenarios. However, according to a TRL analysis of the applications of eye-tracking technology in optometry, most studies fulfill the criteria of the first four levels. These levels are related to proof of concept, whereby research is conducted in a laboratory setting in a controlled environment to emphasize that this new technology is valid. Results are presented as measures of specific parameters or metrics.

While several studies have attempted to utilize eye movement measurements in real-world scenarios, such as face recognition in sports or driving (Ju et al., 2018; Lee et al., 2019; Weaterton et al., 2020), these efforts have only yielded basic metrics, rather than new software or hardware applying eye-tracking technology.

One such study reported on the use of a DIVE device (Pueyo et al., 2020), a product based on eye-tracking technology that is currently marketed for clinical optometry practice. This device is specifically designed to assess visual function and ocular motility in children. We suggest that in consequence this technology could be graded as TRL level 8 as it is relatively new to the market and not yet widely used.

Eye-tracking devices are still expensive, and their use also requires precision and basic knowledge to avoid handling difficulties leading to erroneous data. In consequence, their clinical applicability in optometry is relatively incipient, and the studies available can be described as pre-clinical. Notwithstanding, the results of some of the studies reviewed here reveal the potential of eye-tracking technology to develop preliminary eye movement models in patients (Fujimoto et al., 2022), as well as vision tests to investigate the impacts of visual training (Cheong et al., 2018). This suggests that this technology can be applied to various stages of clinical practice, including assessment, intervention, and treatment monitoring.

According to the results of our review, eye-tracking systems are set to have an impact on optometry practice, but it is crucial that we continue to work on new ideas to improve on the readiness of this technology, including the development of standardized, simplified validated procedures.

As limitations of our review, we should mention the unavailability of data emerging from optometry eye-tracker studies. This is not the case in other fields such as psychology and neuroscience. This review, however, provides a comprehensive overview for optometry professionals wishing to investigate or apply eye-tracking systems in clinical practice. By providing information on the devices and metrics used, we hope to encourage new lines of research with practical implications for patient care.

Conclusions

The use of eye-tracking devices in optometry has exponentially grown over the past ten years, such that this technology is now used in at least 12 areas of optometry and rehabilitation, but mostly in the areas of technology, and the assessment, treatment, and analysis of ocular disorders.

Eye trackers use data from the visual system and ocular motility information to record the visual behavior of individuals of any age both in natural and controlled environments, thus expanding possible applications from laboratory settings to clinical practice.

We propose that these tools should be incorporated more actively in optometry, both in research and clinical applications, as they offer robust objective information about an individual’s vision in terms of optometry and visual function, with the ultimate goal of improving visual health services and our understanding of the vision process.

For the use of eye trackers in clinical practice, it is important that professionals have precise knowledge of the characteristics of the software and hardware used to ensure the acquisition of valid data while considering their limitations. It is especially important that new procedures become standardized, simplified in their application, and validated. It is clear that eye-tracking systems will gradually gain popularity in the optometry field, not only for assessment but also for treatment and training.

Ethics and Conflict of Interest

The authors declare that the contents of this article are in agreement with the ethics described in http://biblio.unibe.ch/portale/elibrary/BOP/jemr/ethics.html and that there is no conflict of interest regarding its publication.

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Appendix 1. Main devices and metrics used in the different areas of optometry

Application area	Devices used	Metrics	Benefits of eye-tracker technology Limitations and methodological aspects	References
Nystagmus	-Eyelink 1000 (1000 Hz) (n=2) -IRIS limbal tracker (100 Hz) -Pupil- Labs head-mounted eye tracker (Berlin, Germany)	-Fixations /Fixation stability (n=2) -Eye displacement -Calibration parameters	- Improved diagnosis - Nystagmus waveform characterization Small sample size Visual function not recorded in some reports No control group Statistical analysis: correlation coefficients, coefficients of variation, test-retest variability. These data missing in 3 reports	Thomas et al. (2022) Abadi et al. (2021) Norouzifard et al. (2020) Rosengren et al. (2020a)
Visual acuity	-Optics Scanning Laser Ophthalmoscopy- based microstimulation -Tracking Scanning Laser Ophthalmoscope (TSLO) -Tobii Glasses 1 mobile head-mounted eye tracker (Tobii Technology, Inc., Falls Church, VA) (n=2), -Eyelink 2000. (1000 Hz) (SR Research, Mississauga, Ontario, Canada) (n=2)	-Fixations/small fixations (n=4) -Eye position -Gaze transitions -Gaze direction -Eye pursuit/ smooth pursuit (n=2) -Kinetic visual acuity -Dynamic visual acuity -Velocity -Saccades	-Visual performance and visual acuity assessment Small population samples (<10) Visual function not recorded in some reports Control group in only 1 report Statistical analysis: ANOVA, correlation tests, bivariate correlation coefficients	Domdei et al. (2021) Freedman et al. (2019) Chen & Yeh (2019) Freedman et al. (2018) Ağaoğlu (2018) Palidis et al. (2017)
Visual field	-Glaucoma Module of the Spectralis SD-OCT(Heidelberg Engineering, Heidelberg, Germany) -Tobii TX300 -Eyelink 1000 remote (SR Research, Ontario, Canada) (n=5) -Tobii IS-1 eye tracker -Tobii X50 eye tracker	-Fixations (n=3) -Smooth pursuit/ pursuit eyemovementt (n=4) -Gaze tracking/eye gaze (n=2) -Saccades (n=3)	-Detection of visual field defects -Impact of peripheral vision loss -Visual field loss characterized -Visual field loss in daily life Small population samples (<50) Visual function not recorded in some reports Control group in only 1 report BCEA formula reported Statistical analysis: median, linear-mixed-effects model, ANOVA, correlation coefficients	Liu et al. (2021) Chow-Wing-Bom et al. (2020) Woutersen et al. (2020) Grillini et al. (2018) Murray et al. (2018) Barraza-Bernal et al. (2017a) Barraza-Bernal et al. (2017b) Liu et al. (2017) Shanidze et al. (2017)
Amblyopia/ strabismus/vergences	-Eyelink 1000 remote (SR Research, Ontario, Canada) (500 Hz) (n=9) -Tobii EyeX. 60 Hz	-Fixational saccades/ saccades (n=3) -Fixational stability/ Average fixation duration/ Number of	- Impact of treatment -Visual search performance -Study of fixation stability	Aizenman & Levi (2021) Satgunam et al. (2021) Murray et al. (2022)

	-iView X, (SensoMotoric Instruments) (60 Hz) (n=2= -ViewPoint EyeTracker system (Arrington Research, Scottsdale, AZ) (350 Hz) -Clinical Eye Tracker system (Version 18.04, Thomson Software Solutions, Hatfield, UK) 780 Hz) -SMI Red250 tracker -SCAN RK-826PCI binocular tracking system (ISCAN, Woburn, MA) (n=2) -Eye-tracker embedded in the stereoscopic virtual reality system EVA (Eye and Vision Analyzer, Davalor Salud, Spain) -Others non-specific: Dual Purkinje image eye tracker	fixations/Time of fixations/Fixations (n=7) -Run count -Eye and gaze position -Eye position (n=7) -Peak velocity -Smooth pursuit -Binocular gaze position -Saccades amplitude -Vergence eye movements (n=2) -Symmetrical disparity vergence -Saccades -Eye movements -Pupil size -Pupil response	-Strabismus diagnosis -Study of ocular deviation -Measurement of heterophoria Small (<50) and large (160>) sample sizes Pre-post evaluation in only 1 report Use of real images Control group used in only 1 report Visual function not recorded in some reports Influence of aging BCEA formula reported Statistical analysis: Levene's and Mauchly's tests, ANOVA, Welch's test, K-S test, paired t-test, Friedman test, Spearman's rank correlation, means, standard deviation, Wilcoxon rank sum test, independent t-test, simple correlation, Shapiro-Wilk-test, U Mann-Whitney test, Pearson correlation, linear regression analysis, one sample t-test	Al-Haddad et al. (2019) Kelly et al. (2019) Tsirlin et al. (2018) Zrinscak et al. (2021) Economides et al. (2021) Mihara et al. (2020) Adams et al. (2017) Kim et al. (2022) Mestre et al. (2021) Gantz & Caspi. (2020) Ramakrishnan & Stevenson (2020) Namaeh et al. (2020) Mestre et al. (2018) Alvarez et al. (2017) Feil et al. (2017) Mestre et al. (2017)
Technology/visual equipment/virtual and augmented reality/videogames	-Vive Pro Eye (HTC Corporation) Head Mounted Display with eye-tracking capability -EyeLink 1000 Plus eye tracker (SR Research, Ontario, Canada) (1000 Hz) (n=3) -VOG (EMR-9, NAC Image Technology Inc., Tokyo, Japan) -Tobii Nano eye tracker (Tobii Technology, Sweden) (60 Hz) -Eyecatcher hardware with a Tobii EyeX (Tobii Technology, Stockholm, Sweden) (n=2) -Saccadic Vector Optokinetic Perimetry (SVOP) -Tobii TX300 eye tracker (n=2= -EyeTurn mobile app	-Fixation / Fixed vision trajectory/ fixation stability (n=10) -Saccades /saccades amplitudes/frequency of saccades (n=3) -Microsaccades -Horizontal gaze -Smooth pursuit (n=3) -Calibration -Eye positions (n=2) -Time of reading -Eye deviations in a horizontal direction -Gaze angles -Head translation/head rotation	-Visual performance -New methods of calibration -Validation of new eye-tracker -Development of virtual reality -Smartphone application -Improved image quality in OCT-A Small (<10) and large (162>) sample sizes Control group included in some studies Pretest-postest in only 1 report Visual function is not registered in some papers Statistical analysis: paired t-test, Kruskal-Wallis test, Mann-Whitney test, linear regression, simple correlation, Pearson`s correlation test, Bonferroni test, Shapiro-Wilk test, Wilcoxon rank sum test Limitations reported: sample size	Fujimoto et al. (2022) Essig et al. (2021) Love et al. (2021) Hirota et al. (2021) Mao et al. (2021) Rosengren et al. (2020b) Jones (2020) Tatham et al. (2020) Kim et al. (2019) Jones et al. (2019) Esfahlani et al. (2019) Pundlik et al. (2019) Hirasawa et al. (2018) Cheong et al. (2018) Albert et al. (2017) Chopra et al. (2017) Lauermann et al. (2017) Murray et al. (2017)

	-Tobii glass II (TobiiTechnology, Stockholm, Sweden) 50 Hz -SMI eye tracker (250 Hz) -OCT-system (AngioVue, RTVue XR Avanti SD-OCT, Optovue,Fremont, CA, USA) (n=2) -Tobii IS-1 model (Tobii Technology, Stockholm, Sweden -Others non specific: Own wearable Display Prototype			
Eye movements/saccades/smooth pursuit/ fixations/microsaccades/processing speed/ gaze stability	-Adaptive Optics Scanning Laser Ophthalmoscope (AOSLO) 960 Hz (n=2) -Eye-movement Real-time Integrated System (EyeRIS) -Dual Purkinje Image (DPI)method, a generation 6 analog DPI eye tracker (Fourward Technologies). (n=2) -EyeLink1000 (SR Research, Ottawa, Ontario, Canada) (1000Hz) (n=8) -iView XTM High Speed 1250 IT -Mobile eye tracker (SMI BeGaze; SensoMotoric Instruments) -Sensor motoric instruments eye tracking glasses (SMI ETG) 120 Hz - Tobii T60XL eye tracker (Tobii Corporation, Sweden) - Infrared eye tracker (USB-220, Arrington Research, Scottsdale, AZ) - Eye Tracking Glasses 2.0 (ETG 2.0; SensoMotoric Instruments, Teltow, Germany) 60 Hz - Monocular eye-tracking system, EyeSeeCam, 220 Hz (ESC; EyeSeeTech GmbH, Furstenfeldbruck, Germany) - Others non-specific: 1.A built high-resolution binocular eye tracker using two USB3 infrared monochrome cameras having 640x480 pixel	-Fixations/fixation duration /reaction time to fixation (n=10) -Saccades /pursuit saccades/saccades amplitude (n=7) -Eye position/gaze position stability (n=2) -Microsaccades (n=6) -Monocular eye movements -Binocular eye movements -Postural sway -Head movements -Vertical and horizontal rotations of the eye	Compare fixational eye movements Study how microsaccades work Study patterns of fixations Study eye movements in children Study human saccades Integrating an eye-tracker into an eye-implant for blind people Characterize gaze stability Small (<20) and large (241>) sample sizes Sample size: arbitrary size in only 1 report Pilot study in only 1 report Visual function is not registered in some papers Eye-tracking paradigm was reported. Statistical analysis: correlation test, mean, median, standard deviation, Shapiro-Wilk test, Welch's test, ANOVA	Bowers et al. (2021) Intoy et al. (2021) Nanjappa & McPeek. (2021) Belyaev et al. (2020) Raveendran et al. (2020) Poletti et al. (2020) Chaudhary et al. (2020) Ivanchenko et al. (2019) Pel et al. (2019) Kelly et al. (2019) Kwon et al. (2019) Badler et al. (2019) González et al. (2019) Goettker et al.(2019) Fang et al. (2018) Caspi et al. (2018) Ratnam et al. (2018) Seemiller et al. (2018) Sheynikhovich et al. (2018) Amit et al. (2017) Vater et al. (2017)

	resolution, and sampling images at 400 Hz (The Imaging Source, Model DMK33UX174) 2. Binocular Dual Purkinje Image eye tracker Revolving Field Monitor, a specially designed eye-coil apparatus			
Ocular pathology/low vision/glaucoma/stardgart disease/AMD/diabetic macular edema	-Retinal image-based eye tracker, the TSLO (C. Light Technologies, Inc., Berkeley, CA) - Eyelink 1000. (SR Research, Ontario, Canada) (n=4) - Tobii Glasses Pro 2 - Iscan ETL 100Hz (MA, USA) - Stereoscopic eye tracking system with two USB 3.0 cameras and two infrared light. 300 Hz - Tobii T60XL (Tobii Corporation, Danderyd, Sweden - Tobii TX300eye-tracker (Tobii Technology, Danderyd, Sweden) (n=3) - Spectralis self-acting eye-tracking (eye tracker) - iView X™ video-based eye tracker - External infrared eye-tracking camera (Arrington Research,Inc., Scottsdale, AZ, USA - video-based eye-tracker (Series 2020; El-Mar, Inc., Toronto, ON, Canada) 120 Hz	-Fixations/fixation time/reaction time to fixation/fixation duration/ spread of fixation locations/monocular and binocular fixations (n=10) -Saccades/saccade amplitude (n=9) -Microsaccades -Blinks -Drifts -Smooth pursuit -Gaze position (n=3) -eye movements (n=2) -Horizontal and vertical variance	Evaluate fixational eye movements in people with ocular diseases. Determine eye movement differences. Visual functions assessment Type of study: prospective experimental cohort study (n=1), longitudinal study (n=1), case control study (n=1), cross-sectional study in only 1 report Small (<50) and large (187>) sample sizes Control groups were used in some papers. Some do not describe population . Visual function is registered. BCEA formula was calculated. Statistical analysis: Mann-Whitney U test, two-sample t test, Spearman`s correlation, chi-square test, coefficient of variation, test-retest variability, ANOVA, Shapiro-Wilk test	Leonard et al. (2021) Ballae Ganeshrao et al. (2021) Garric et al. (2021) Giacomelli et al. (2020) Senger et al. (2020) Titchener et al. (2020) Barsingerhorn et al. (2019) Lee et al. (2019) Kooiker et al. (2019) Asfaw et al. (2018) Laude et al. (2018) Gao & Sabel. (2017) Abadia et al. (2017) Lee et al. (2017) Jakobsen et al. (2017) Shivdasani et al. (2017) Tarita-Nistor et al. (2017) Alberti & Bex. (2017)
Assessment/diagnosis/visual function/Rehabilitation/training	-Tobii 4c eye tracker. 90 Hz (n=5) -Tobii-X2-30 eye tracker -Eye tracker inside Saccadic Vector Optokinetic Perimetry (SVOP) -Tobii IS-1 (TobiiTechnology, Stockholm, Sweden) 40-H - Mobile Eye Tracker (Mobile EBT®)	-Eye movements -Eye velocity -Pupil size (n=3) -Horizontal gaze/gaze data (n=4) -Blink rate (n=3) -Eye position	Colour vision assessment Training in visual rehabilitation Quantify saccades, smooth pursuit and contrast sensitivity Visual assessment in infants and people with disabilities. Nystagmus treatment Training visual abilities Automatic visual impairment detection system	Taore et al. (2022) Awada et al. (2022) Wilhelmsen et al. (2021) Brodsky & Good. (2021) Xie et al. (2021) Mooney et al. (2021) Perperidis et al. (2021) Chatard et al. (2019)

	- Generation 6 Dual Purkinje Image (DPI) eye tracker (Fourward Technologies) - Eye-link 1000+ eye-tracker (SR Research) (n=2) - Tobii Pro X3-120 (Eye Tracker; Tobii AB Inc., Danderyd, Sweden) - Tobii X2–60 eye tracker - SMI eye 94 tracker (SensoMotoric Instruments GmbH, Teltow, 95 Germany) (n=2) - HMD-ET. 240 Hz - Tobii PRO TX-300 (n=3) - Comprehensive Oculometric Behavioral Response Assessment (COBRA) - Nidek MP-1 microperimeter (Navis, Nidek Technologies, Italy)	-Smooth pursuit/pursuit latency/ pursuit (n=3) acceleration (n=2) -Saccades/ saccades amplitude/ saccades frequency (n=5) -Microsaccades -Monocular central fixation/fixations (n=5) - Time to looking at targets or distractors - Eye movements (n=3) - Reading - Fixations	Type of study: prospective study in only 1 report Small (<60) and large (187>) sample sizes Some do not describe population Visual function is registered. Statistical analysis: ANOVA, independent test, Kruskal-Wallis test, paired t-test, Pearson`s correlation coefficient, Spearman`s correlation, paired Student`s t- test, Mann-Whitney test	Shelchkova & Poletti. (2020) Ramesh et al. (2020) Weaterton et al. (2020) Wan et al. (2020) Wang et al. (2020) Tatiyosyan et al. (2020) Hotta et al. (2019) Axelsson et al. (2019) Shelchkova et al. (2019) Wen et al. (2018) Mooney et al. (2018) Ryu & Wallraven (2018) Liston & Stone. (2017) Liu et al. (2017) Schönbach et al. (2017) Yow et al. (2017)
Surgery	-Mobile T2 (Suricog, France) 300 Hz - Motion-tracking software (PHACOTRACKING,Guildford, United Kingdom) -Others non-specific: Custom-built eye tracker	-Fixation /fixation light tracking - Bell's reflex - Saccades -Oscillations - Nociceptive reflex movement - Nystagmus	Evaluate differences in eye movements Small sample size (<10) Visual function is not registered in some papers BCEA formula was calculated. Statistical analysis: descriptive statistic	Perrin-Fievez et al. (2018) Reinstein et al. (2018) Coletta et al. (2018)
Refractive error	- Eyelink 1000 Plus, SR Research, Ontario, Canada) 500 Hz (n=2)	-Horizontal and vertical eye movements -Centre of rotation of the eye - Eye position - Eye velocity -Saccades -Fixation stability	Study the eyeball rotation in refractive error. Study refractive error Small sample size (<59) Statistical analysis: ANOVA Limitation reported: calibration, reflections on surface lenses.	Ohlendorf et al. (2022) Doustkouhi et al. (2020)
Reading	-MAIA microperimetry	-Fixation/ fixation duration / first fixation	Analyze the effect of text presentation, color, and size in eye movements.	Bowman et al. (2021)

	- Eyelink II (SR Research, Mississauga, Ontario, Canada) 500 Hz - SMI eye tracker (RED 250 m, SensoMotoric) - Tobii TX300 eye tracker (Tobii Tecnoloy Danderyd, Sweeden) 300 Hz (n=4) - Mobile T2 (SuriCog, France) 300 Hz - Tobii XL120, 120Hz	duration/fixation stability (n=7) -Gaze duration -Selection regression-path duration (n=2) - Reading time/ reading speed (n=3) - Saccades/number and amplitude of saccades (n=4) - Blinks	Measure reading rates Small (<50) and large (120>) sample sizes Sample size calculated with Cochran`s formula in only 1 report Control group was used in some papers. Visual function is not registered in some papers Statistical analysis: Shapiro-Wilk-test, Wilcoxon rank sum-test, ANOVA, Mann-Whitney test, chi-square Limitations reported: The use of glasses and sample size.	Hyona et al. (2020) Wertli et al. (2020) Fadzil et al. (2019) Murata et al. (2017) Ridder et al. (2017) Ryu & Wallraven. (2017) Vinuela-Navarro et al. (2017)
Sport vision/ locomotion	-EyeLink 1000 (SR Research Ltd., ON,Canada)	-Saccades -Eye response time	Effects of visuomotor training Small sample size (<56) Visual function is not registered in some papers Statistical análisis: descriptive statistic (mean, standard deviation), comparative statistic	Ju et al. (2018)
Oculomotor deficits/ oculomotor responses	-Device for an Integral Visual Examination (DIVE) 60 Hz - C-ETD (Chronos Inc., Berlin)	-Fixations -Saccades -Binocular tracking - Horizontal and vertical eye movements - Torsional eye movements	Study oculomotor behavior in children and young people Small sample size (<29) BCEA formula was calculated. Statistical analysis: mean, standard deviation, Kruskal-Wallis test, MANOVA, Shapiro-Wilks test	Pueyo et al. (2020) Wibble et al. (2020)

Appendix 2. Relevant information of each included study

Year	Main Objective	Subjects	Device Characteristics	Metrics	Method aspects	Reference
2022	Get more knowledge about their functional vision as a fundament for educating pupils with albinism	3 subjects (10-12 years old)	Tobii Eye Tracker 4 C	Pupil size Horizontal gaze	Environment: Iluminating and reflects were controlled. Stimuli: Horizontal smooth pursuit task. Distance:60 cm E-T benefits: could reveal if any child could really keep a fixed gaze position during reading as this often results in abnormal head postures and neck problems	Wilhelmsen et al.
2022	Develop a simple objective test of functional colour vision based on eye movements made in response to moving patterns	34 participants (17 females, 17 male, 17–65 years), of which 23 were normal trichromat controls, 9 were deuteranopes and 2 were protanopes	Tobii 4c Eye tracker. 90 Hz	Eye movements Eye velocity Pupil diameter	Laptop 1920x1080 pixels, at 40 cm Stimuli: DEM test E-T benefits: Advances in software-based eye tracking running on many devices equipped with front-facing cameras their test could become a simple, reliable, automated colour vision assessment that could be downloaded for use by clinician.	Taore et al.
2022	Assess the effects of monocular, binocular, and dichoptic viewing on FEMs and eye alignment in patients with and without fusion maldevelopment nystagmus (FMN)	34 patients with amblyopia and 7 healthy controls Subjects were randomly selected Control group	EyeLink 1000 Chin rest	Fixational saccades Fixation stability Intersacadic microsaccades	Equipment: Monitor of 1280 x 800 pixels Binocular horizontal and vertical eye positions were measured. Dark room Stimuli: A white circular target was used.	Murray et al.

					Calibration and validation of each eye was done. Statistical analysis: MatLab was use to analyze eye positions, with Engbert and Kleigl algortih, SPSS to statistical analysis, Test Kolmogorov-Smirnov, Levene`s test and Mauchly^s tests ANOVA. E-T benefits: FEM abnormalities modulate with different viewing conditions as used in various amblyopia	
2022	Establish a quantitative evaluation and comparison of fixation stability, as measured by an eye tracker, using image-based areas determined by the bivariate contour ellipse area (BCEA), kernel density estimation (KDE), and Scanpath methods.	45 and 20 participants with abnormal and normal phoria (29 women, mean age 21-5 +/- 1.9 years)	Clinical EyeTracker system (Version 18.04, Thomson Software Solutions, Hatfield, UK) 70 Hz	Fixation stability Binocular gaze position	Data analysys: Paired-sample t-test in SPSS Wilconxon text	Kim et al.
2022	Conduct preliminary eye and head mount display (HMD) movement measurements to collect primary data to create a Spatio-temporal virtual reality(VR) navigation system	11 university students (aged 21-22 years)	Vive Pro Eye (HTC Corporation), and Head Mounted Display with eye-tracking capability	Fixation Fixed vision trajectory microsaccades	Stimuli: fixed vision, random bouncing vision, and liner motion chasing.	Fujimoto et al.
2022	Study if the training with optic flow stimuli promotes recovery in cortical blindness	-	-	-	E-T benefits: permits assessment and training in cortical blindness.	Awada et al.
2022	Study a voluntary Flutter Presenting During Ophthalmoscopy in an unusual case	1 male with autism 20 years old	Eyelink 1000 (SR Research, Ottawa, ON, Canada) 1000 Hz A chinrest was used.	Fixations Monocular fixations	E-T benefits: permits register of voluntary flutter to diagnosis between nystagmus or other conditions. Stimuli: fixation in five points, monocular fixation in primary position, binocular	Thomas et al.

					convergence, seven minutes central fixations.	
2021	Study Fast and nonuniform dynamics of perisaccadic vision in the central fovea	8 subjects (6 females, age range 23-33 years)	Eye-movement Real-time Integrated System (EyeRIS) Dual Purkinje Image (DPI)method, a generation 6 analog DPI eye tracker (Fourward Technologies).	Microsaccades Saccades	Two-tailed nonparametric bootstrap test Head-rest Stimuli: 30 gray dots randomly distributed within 2º Based-event recorded by EyeRIS	Intoy et al.
2021	Determine whether fixational stability can be used as an objective marker for the recovery of visual function in amblyopia	5 children with amblyopia (mean age 8.2 years) 5 normally sighted children	Eyelink II 500 Hz	Fixational Saccades	E-T benefits: permits measure treatment in amblyopia. Stimuli: 1º colorful smiley face for 20 seconds. Pre and post evaluation	Aizenman, A. & Levi, D.
2021	Present a new computational approach to analyze nystagmus waveforms	5 adults, 1 male (age range 22-46 years)	IRIS limbal tracker.(Skalar Medical, Delft, The 1 Netherlands). 100 Hz. Head-mounted Video-based infra-red pupil tracking eye tracker. 400 Hz. (Chronos: Skalar Medical, Delft, The Netherlands)	Fixation stability Amplitude saccades		Abadi et al.
2021	Compare saccadic eye movements between high-tension glaucoma (HTG), normal-tension glaucoma (NTG), and primary angle-closure glaucoma (PACG)	52 subjects 15 HTG, 14 PACG, 8 NTG 15 normal controls	Eyelink 1000	Saccades Prosaccades	Gap paradigm 3 target eccentricities Latency, average and peak velocity of prosaccades. E-T benefits: Determine eye movements differences between types of glaucoma	Ballae et al.

2021	Compare and contrast fixational eye movements (FEM) during *active* tasks–those that contain temporal variation and require subject input—and *passive* tasks, where the subject is simply instructed to maintain fixation on a target	8 healthy subjects (3 male, ages range 23 to 53 years)	Adaptive Optics Scanning Laser Ophthalmoscope (AOSLO) 960 Hz	Fixations Microsaccades	Stimuli:fixation targets (Maltese cross, disk, concentric circles, Vernier and tumbling-E letter)	Bowers et al.
2021	Investigate the conjoint effects of color mode and luminance contrast on visual fatigue and subjective preference when using electronic devices under low screen luminance and low ambient illumination at night	60 subjects (25 female)	Tobii-X2-30 eye tracke	Pupil data Blink rate	Stimuli: middle contrast texts, 21 pages with 400 words per page. Statistical analysis. MANOVA E-T benefits: allowed get some guidelines for the design of interaction interface of the electronic devices in a specific illumination condition.	Xie et al.
2021	Compare rapid serial visual presentation (RSVP) and horizontal scrolling text presentation (scrolling) on reading rate and reading acuity in CVL observers and normally-sighted controls with simulated CVL	11 subjects bilateral CVL 16 controls	MAIA microperimetry EyeLink 1000 Pluseye tracker (SR Research, Ontario, Canada) with fixed sampling rate of 1000 Hz	Fixation	Stimuli: rapid serial visual presentation texts, a green fixation dot 4º above the text E-T benefits permits to analyze the effect of the text presentation and font size on reading.	Bowman et al.
2021	Test the vision in subjects with visual impairment	Visual impairment people	-	-		Brodsky & Good.
2021	Assess to what extent the specific cellular organization of the foveola of an individual is reflected in visual sensitivity and if sensitivity peaks at the preferred retinal locus of fixation (PRL)	4 human participants (one female; ages 29, 32, 42, and 42 years)	Optics Scanning Laser Ophthalmoscopy- based microstimulation	Small fixations	Stimuli: small-spot, cone targeted visual stimuli allowed to develop a model of visual sensitivity in the foveola, with distance from the PRL (eccentricity), cone density, and OS length as parameters	Domdei et al.
2021	Develop and validate an automated contrast sensitivity (CS) test using a live- detection of optokinetic nystagmus (OKN)and an adaptive psychometric procedure	15 healthy participants four male, (mean age 24.7 +/- 3)	EyeLink 1000 Pluseye tracker (SR Research, Ontario, Canada) with fixed sampling rate of 1000 Hz	Saccade Horizontal gaze Blink detection	Stimuli: vertically oriented square-wave grating drifting over the horizontal plane with a constant velocity Statistical analysis: Matlab to analyze data	Essig et al.

					E-T benefits: Possibility to use OKN to assess visual performance, visual acuity, visual field	
2021	Investigate saccadic movements in subjects with eccentric fixation due to a deep central scotoma in Stargardt disease (STGD)	10 patients with STGD and 10 healthy subjects (control group)	Tobii Glasses Pro 2	Saccadic eye movements Fixations	Chin rest Stimuli: spot of 1° angular size which started in the center or in four different positions Statistical analysis: two-sample t-test, with equal or unequal variance as appropriate. A paired t-test was used The correlation pattern among saccadic times and psychophysical variables was analyzed using Spearman correlation.	Giacomelli et al.
2021	Estimate the impact of glaucoma on computer use and assess specific adaptations of the graphical interface to this form of visual impairment	49 subjects: 16 patients with primary open-angle glaucoma (mean 62.7 ± 5.6 years of age), 17 age-matched participants (mean 59.1 ± 8.3 years of age), 16 young control participants (mean 23.3 ± 2.1 years of age)	-	Oculomotor behavior	Prospective experimental cohort study Stimuli: ecological computer scenes with 3 enhancement levels (low, medium, and high), determined by gradual modulation of contrast, luminance, and color To improve the interface features to improve visual comfort.	Garric et al.
2021	Analyze the amplitude, direction, and rate of small saccades as a function of vergence demand when testing the near point of convergence.	11 young adults (mean age ± SD: 25.4 ± 2.2 years)	EyeLink 1000 Plus (SR Research)	Eye positions Saccades amplitude Number of saccades per second	Chin rest Statistical analysis: MatLab and SPSS Parametric test, Shapiro-Wilk test, Spearman`s rank order, Mann-Whitney test and Kruskal-Wallis test were used. Stimuli: fixation cross which moved along the midline to elicit symmetrical conver- gence and divergence movements	Mestre et al.
2021	Explore the different eye movement behaviors of people with several types of artificial Visual Field Defects	38 participants with normal vision were recruited to watch a group of videos monocularly	Tobii Nano eye tracker (Tobii Technology, Sweden) 60 Hz	Smooth pursuit Fixations	Stimuli: 41 videos with duration less than 2 minutes.	Mao et al.

	(VFDs), such as hemianopia, altitudinal VFDs, and tunnel vision				Statistical analysis: Non parametric test, Kruskal-Wallis, Mann-Whitney test were used. It was proved in normal people, is unclear if the test works in VFD patients	
2021	Present a novel, properly tested and evaluated eye-tracking based method for manifest strabismus diagnosis is presented.	81 patients, 41 with a diagnosis of strabismus	Tobii EyeX. 60 Hz Dual Purkinje Image eye-tracker	Eye and gaze positions	Distance: 60 cm Stimuli: strabiscope hardware Statistical analysis: SPSS, Kolmogorov-Smirnov	Zrinšćak et al.
2021	Describe a novel approach to grading visual health based on eye movements and evidence from gaze-based tracking behaviors.	14 children (age range 3 to 18 years)	Tobii 4C eye tracker (50–95 cm operating distance; 90 Hz sampling rate)	Gaze data Saccades Pursuits	Distance: 62 cm Stimuli: Visual Ladder program, 5 tasks. Statistical analysis: to detect broad asymmetries in saccade amplitude specifically, independent-tests E-T benefits: Quantify saccades, smooth pursuits,and contrast sensitivity in children of a wide variety of ages and communicative ability,	Mooney et al.
2021	Compare visual field results of the COMPASS fundus perimeter (CMP) and the Humphrey Field Analyzer (HFA) in the same eyes.	124 eyes of 79 patients with glaucoma	Glaucoma Module of the Spectralis SD-OCT(Heidelberg Engineering, Heidelberg, Germany)	-		Liu et al.
2021	Quantify reductions in calibration accuracy relative to fixation eccentricity and suggest a robotic calibration and validation tool.	8 subjects with central field loss (75.1 +/- 12.1) and 7 controls (72.4 /- 5.7)	Eyelink 1000 EyeRobot	Fixations	E-T benefits: New methods of calibration in CFL	Love et al.
2021	Evaluate fixational eye movements (FEMs) with high spatial and temporal resolution following concussion.	99 adolescents and young adults (13 to 27 years old)	Retinal image-based eye tracker, the TSLO (C. Light Technologies, Inc., Berkeley, CA)	Fixations Saccades Drifts	Stimuli: three fixation tasks Statistical analysis: t-test or Mann–Whitney U, Kolmogorov-Smirnov	Leonard et al.

2021	Investigate visual search performance in this cohort with real world images	23 patients (mean age: 10 ± 0.6 years) and 13 controls (10 ± 0.9 years)	Eyelink1000	Saccades count Run count (number of repeating viewing) Average fixation duration	Stimuli: A real world image was displayed on a computer screen along with a search target	Satgunam et al.
2021	Determine how the position of the centre of rotation of the eyeball is related to axial length and refractive error when horizontal and vertical eye movements are performed.	59 subjects (32 females, age range 36.3 +/- 9.1 years)	Custom-built eye tracker	Horizontal and vertical eye movements Centre of rotation of the eye	Statistical analysis: ANOVA	Ohlendorf et al.
2021	Development of a Simple Test of the Slow-To-See Phenomenon in Children with Infantile Nystagmus Syndrome	Patients with nystagmus, diagnosis of learning disability	Eye-link 1000+ eye-tracker (SR Research)	Time looking at targets and distractors	Stimuli: find their own mother or a target face from a selection of faces displayed at once on a tablet and then press the target as fast as possible Statistical analysis: SPSS, Spearman`s rank coefficient. E-T benefits: Use of e-t in clinical trials of nystagmus treatment.	Weaterton et al.
2021	Compare the ocular deviation in patients with intermittent exotropia under conditions of monocular versus binocular occlusion	18 Subjects (11 females, range 8-60 years)	Two video-based eye trackers (iView X; Senso-Motoric Instruments, Teltow, Germany), sampling at 60 Hz	Right and left eye positions	Task: Fixate a target. Stimuli: spot of light 0.5º in diameter. Statistical analysis: paired t-test	Economides et al.
2021	Accurately record the movements of a hand-held target together with the smooth pursuit eye movements (SPEMs) elicited with video-oculography (VOG) combined with deep learning-based object detection using a single-shot multibox detector (SSD)	11 healthy subjects (21.3 +/- 0.9 years)	VOG (EMR-9, NAC Image Technology Inc., Tokyo, Japan	Smooth pursuit eye movements	Stimuli: rabbit-like character, size 10 x 10 cm. Statistical analysis: paired t-test. SPSS program to determine significance differences.	Hirota et al.

2021	Study microsaccades and attention in a high-acuity visual alignment task	11 subjects (six female, age range 25-30 years)	EyeLink1000 (SR Research, Ottawa, Ontario, Canada) at 1000Hz.	Monocular eye movements Fixations microsaccades	Distance: 120 cm Task: 2 experiments, 120 trials ~40 minutes, fixate a target without blink. Detect a letter in a RSVP. E-T benefits: how to microsaccades works in fine acuity tasks	Nanjappa & McPeek.
2020	Determine threshold visual field sensitivities in normal subjects performing saccadic vector optokinetic perimetry (SVOP), a new eye tracking perimeter	113 healthy patients (Mean age 65.9 +/-10.1)	Saccadic Vector Optokinetic Perimetry (SVOP)	-	Comparative study Statistical analysis: Bland-Altman plots, relationships were examined by pointwise linear regression.	Tatham. et al.
2020	Generate a Real-Time Eye Tracking Method for Detecting Optokinetic Nystagmus	6 healthy subjects	Pupil- Labs head-mounted eye tracker (Berlin, Germany)	Eye displacement	Distance: 1.5 meters E-T benefits. Detect optokinetic nystagmus	Norouzifard et al.
2020	Assess oculomotor behavior in children adopted from Eastern Europe, who are at high risk of maternal alcohol consumption	29 adoptees and 29 age-matched controls	Device for an Integral Visual Examination (DIVE) 60 Hz	Fixations Saccades	Stimuli: High contrast cartoon on the centre of the screen, short fixational tasks. Fixations and saccades were identified with a dispersion-based algorithm. Fixation stability calculated with BCEA Statistical analysis: mean, SD, ranges. Shapiro-Wilk test, Kruskal- Wallis test to compare, student´s t-test E-T benefits: allows better assessment of oculomotor skills.	Pueyo et al.
2020	Study the effect of refractive error on optokinetic nystagmus	Experiment 1. 20 participants (20-35 years old) Experiment 2. 25 participants (19-51 years old)	Eyelink 1000 Plus (SR Research, Ontario, Canada) 500 Hz	Saccades	Distance: 1m Stimuli: generated in Statistical analysis: Matlab, spatial filtered-two dimensional random noise patterns. Limitations: an eye-tracker that could measure EM independent from calibration	Doustkouhi et al.

					and the reflections from surface lenses is needed.	
2020	Develop an OKN-based virtual diagnosis tool to estimate contrast sensitivity automatically without the active cooperation of the patient as well as the practitioner within 3.5 minutes.	12 healthy subjects with normal or corrected to normal vision (mean age 25.2 +/-1.7)	SMI eye 94 tracker (SensoMotoric Instruments GmbH, Teltow, 95 Germany)	Eye movements	Stimuli: fixation point target and motion sequence Statistical analysis: Matlab E-T benefits: good tool to screen visual function in patients with difficulties.	Tatiyosyan et al.
2020	Examine whether assessing the visual functioning of the “intact” ipsilesional visual field can be useful to understand difficulties experienced by patients with visual field defects	18 patients (15 males,) with visual field defects owing to postchiasmatic brain lesions. 18 control subjects	Eyelink 1000 remote (SR Research, Ontario, Canada)	Gaze tracking	Stimuli: UFOV test Statistical analysis: Matlab, mixed-design ANOVA. e-t: stimuli UFOV is good for evaluating visual functioning.	Woutersen et al.
2020	Analyze detailed contrast sensitivity function measured with a nonverbal procedure called “Gradiate”	60 subjects (34 females, age range 11 to 74 years)	Tobii 4C eye tracker (operating distance of 50–95cm; sampling rate of 90 Hz)	Smooth tracking	Stimuli: Five targets were presented to the observer simultaneously in each Gradiate trial. Python was used to generate stimuli and extract data Limitations: calibration of e-t	Mooney et al.
2020	Observe the change in horizontal smooth pursuit in patients with intermittent exotropia before and after strabismus surgery.	9 patients (mean age, 22.2 ± 13.9 years)	ViewPoint EyeTracker system (Arrington Research, Scottsdale, AZ) at a sampling rate of 350 Hz	Velocity and amplitude of Smooth pursuit Eye position	Head positioner was used. Statistical analysis: SPSS, Friedman test, Spearman`s rank correlation	Mihara et al.
2020	Study accuracy and precision of small saccades	11 subjects (5 emmetropic, 3 females)	Dual Purkinje imaging for high-resolution eye-tracking	Gaze localization Saccades	Distance: 126 cm. Head rest	Poletti et al.

2020	Evaluating the impact of asymmetric peripheral vision loss on everyday function	20 healthy adults (mean age 26.2 years) with normal vision	FOVE0 Eye-Tracking VR headset (FOVE Inc., San Mateo, CA, United States) 70 Hz	Eye movements Head movements	Stimuli: Search environments consisted of 15 household rooms Statistical analysis: Linear-Mixed-Effects model. Matlab	Chow-Wing et al.
2020	Investigate visual fixations and postural sway in response to increasingly complex visual environments in healthy adults and adults with motion sensitivity	20 healthy adults 20 adults with motion sensitivity	Mobile eye tracker (SMI BeGaze; SensoMotoric Instruments) Sensor motoric instruments eye tracking glasses (SMI ETG) 120 Hz	Visual fixations Postural sway Body kinematics	Stimuli: Python, 6 tasks, each lasting 70 seconds Sample size: arbitrary size. Statistical analysis: descriptive statistics, Kolmogorov-Smirnov test.	Chaudhary et al.
2020	Establish normative data for objective measures of disparity vergence and saccades in children using an objective binocular eye movement tracking system	118 subjects (age range 9 -17 years)	SCAN RK-826PCI binocular tracking system (ISCAN, Woburn, MA)	Symmetrical disparity vergence Saccades	Stimuli: vertically oriented visual stimulus target Data analysis: Matlab, SPSS, Shapiro-Wilk test, descriptive statistics	Namaeh et al.
2020	Propose a signal quality metric for nystagmus waveforms, the normalized segment error (NSE)	3 subjects with nystagmus	EyeLink 1000Plus	Calibration Fixations Smooth pursuit Saccades	E-T benefit: characterization and comparison of nystagmus waveform patterns	Rosengren et al.
2020	Investigate oculomotor behavior in response to dynamic stimuli in retinal implant recipients	3 suprachoroidal retinal implant recipients	Head-mounted eye tracker (Arrington Research,Scottsdale, AZ, USA) 60 Hz	Smooth pursuit		Titchener et al.
2020	To compare the impact of unilateral versus bilateral Age-related Macular Degeneration (AMD) on saccadic movements, and to show the effect of visual search training on these eye movement performances in AMD subjects	13 elderly unilateral AMD (mean age 74.6 +/- 1.6 years) 15 elderly bilateral AMD (mean age 74.2 +/- 1.2 years) 15 healthy age-matched control (mean age: 70.9 +/- 1.3 years)	Mobile Eye Tracker (Mobile EBT®)	Horizontal saccadic	Dark room Head rest Data: time, number of omissions and error in saccades. Statistical analysis: Kruskal-Wallis and posthoc tests.	Chatard et al.

2020	Synchronization of a Removable Optical Element with an Eye Tracker for Heterophoria Measurement	30 normal sighted subjects (mean age 24.50 +/- 2.20)	SMI Red250 tracker	Eye position	Statistical analysis: Pearson correlation, Anderson-Darling normality test. Matlab	Gantz & Caspi
2020	Study the dependence of the correlation of time spent in fixations on the degree of distortion of texts when reading.	-	iView XTM High Speed 1250 IT	Fixations Saccades		Belyaev et al.
2020	Explore how visual and vestibular acceleration affect roll-plane oculomotor responses, including their addiative effect	13 healthy volunteers (6 female, mean age 25 years)	C-ETD (Chronos Inc., Berlin)	Binocular tracking Horizontal and vertical eye movements Torsional eye movements.	Stimuli: a central fixation point (0.32 cm in diameter) surrounded by 38 inclined white lines tilted at 45 degrees. Statistical analysis:MANOVA, Shapiro-Wilk´s tests, SPSS	Wibble et al.
2020	Explore the feasibility of applying the SMI RED eye tracker bar to record eye movements in 10- and 11-year-old children while reading a text	33 subjects (19 aged 10 years, 14 aged 11 years) normally sighted children	SMI eye tracker (RED 250 m, SensoMotoric)	Reading time, reading speed, total number of saccades or fixations.	E-T benefits: Allows to recognize reading difficulties and monitoring treatment effects. Limitations: the use of glasses and the sample size	Wertli et al.
2020	Evaluate the saccadic movements (SM) in Primary open angle glaucoma (POAG) patients and healthy controls during an exploratory VS digit-based task	7 POAG subjects 6 controls	Iscan ETL 100Hz (MA, USA)	Saccadic movements	Statistical analysis: Correlation test	Senger et al.
2020	Observe the eye movement behaviors in patients with cataract during performance-based tasks including visual search, face recognition and reading tasks.	30 Subjects with bilateral age-related cataract. 22 age-matched controls.	Tobii Pro X3-120 (Eye Tracker; Tobii AB Inc., Danderyd, Sweden)	Eye movements Fixations	Prospective study. Three tasks: visual search, face recognition, reading task. Statistical analysis: paired Student's t-tests, Mann-Whitney U test, Spearman correlation. SPSS.	Wan et al.
2020	Test the effects of alternate occlusion flicker on symmetrical vergence responses to disparity steps.	-	Dual Purkinje image eye tracker	Vergence eye movements		Ramakrishnan & Stevenson.

2020	Assess whether the pattern and/or magnitude of fixational eye movements differed when a visual discrimination task was performed at the point of fixation versus in peripheral vision	14 subjects (9 females, mean age 38 +/- 7 years)	EyeLink 1000 Plus(SR Research, Ottawa, ON, Canada) at 1000 Hz	Fixations	Stimuli: Monocular tumbling E orientation discrimination task at three different eccentricities: 0° (fovea), 5°, and 10°	Raveendran et al
2020	Optical health analysis of visual comfort for bright screen display based on back propagation neural network	30 subjects (15 female)	Tobii X2–60 eye tracker	Pupil size Blinks	Stimuli: target and three distractors simultaneously presented Statistical analysis: paired t test, Pearson correlation coefficient	Wang et al.
2020	Assess amblyopic children's covert endogenous attention with a classical spatial-cueing paradigm and compared performance across eyes and between amblyopic and visually typical children	11 visually typical children 13 amblyopic children	Tobii4C eye tracker (Tobii Technology, Frankfurt am Main,Germany)	Paradigm: shape speed Monocular central fixation	Stimuli: target and three distractors simultaneously presented Statistical analysis: paired t test, Pearson correlation coefficient	Ramesh et al.
2020	Examine the recognition of novel and lexicalized compound words during sentence reading	26 subjects with normal or corrected to normal vision	Eyelink II (SR Research, Mississauga, Ontario, Canada) 500 Hz	Fixation duration Gaze duration First fixation duration Selective regression-path duration	Stimuli: Sixty existing two-constituent compound words and 60 novel two-constituent Finnish compound words	Hyona et al.
2020	Examine the feasibility of saccadic vector optokinetic perimetry (SVOP), an automated eye tracking perimeter, as a tool for visual field (VF) assessment in infants	13 healthy infants (ae range 3.5 and 12 months)	Eye tracker inside Saccadic Vector Optokinetic Perimetry (SVOP) Tobii IS-1 (TobiiTechnology, Stockholm, Sweden) 40-H	Eye position	Stimuli: circular spots with angular diameter of 0.43º, 0.86º and 1.72º Test patterns of up to 40 points were used.	Perperidis et al.
2020	To describe, validate, and provide preliminary normative data for an open-source eye-movement perimeter (Eyecatcher)	64 normally sighted adults (43 females, mean 24.3 years)	Eyecatcher hardware with a Tobii EyeX (Tobii Technology, Stockholm, Sweden)	Fixations	Stimuli: 24-2 Threshold test, usingGoldmann III/0.43° stimuli Statistical analysis : .MatlabMann-WhitneyUtest	Jones.

2020	The effect of refractive error on optokinetic nystagmus	Experiment 1: 20 participants (20-35 years old) Experiment2.. 25 subjects (19-51 years old)	Eyelink 1000 Plus, SR Research, Ontario, Canada) 500 Hz	Eye position Eye velocity Saccades	Stimuli: t two-dimensional random noise patterns. 2 experiments. Statistical analysis: Matlab	Doustkouhi et al.
2019	Study the Fixation instability during binocular viewing in anisometropic and strabismic children	160 children age 4–12 years with treated esotropia and/or anisometropia (98 amblyopic, 62 nonamblyopic) were compared to 46 age-similar control	Eyelink II (SR Research, Mississauga, Ontario, Canada) 500 Hz	Fixation stability	Distance: 115 cm. Monocular calibration. Statistical analysis: Matlab. Bivariate contour ellipse area to measure fixation stability. ANOVA	Kelly et al.
2019	Present a near-eye augmented reality display with resolution and focal depth dynamically driven by gaze tracking	60 people	Own wearable Display Prototype	-	Data analysis: paired t-test, independent t-test, simple correlation. SPSS was used.	Kim et al.
2019	Evaluate a smartphone application (app) performing an automated photographic Hirschberg test for measurement of eye deviations.	25 nonstrabismic normally-sighted subjects (age range 20- 40 years)	EyeTurn mobile app	Eye deviations in horizontal direction Gaze angles	3 experiments	Pundlik et al.
2019	Effects of blue light on dynamic vision	16 ypung male adults (age range 25.9 years) with normal or corrected to normal binocular vision	Eyelink 2000. 1000 Hz SR Research,Mississauga, Ontario, Canad	Eye pursuit Kinetic visual acuity Dynamic visual acuity fixation	Stimuli: A square (22.72° × 22.72°) in blue or orange as background was displayed during the whole experiment. Three randomly chosen numbers (0–9, size 1.89°) moved sequentially. Statistical analysis: SPSS, ANOVA	Chen & Yeh.
2019	To detect eye tracking abnormalities in children with strabismus in the absence or presence of amblyopia	50 children with strabismus (24 with amblyopia) (mean age 10.66 +/-2.90 years) 50 controls (mean age 10.02 +/- 2.75 years)	-	Paradigms: 1. Distance/near 2. Reading 3. Location Identification 4. Video	E-T benefits: detect eye movements deficits	Al- Haddad, C. et al.

				Metrics: number and time of fixations		
2019	Study interocular correlations of drifts when subjects fixated on a stationary target.	8 naïve subjects	A built high-resolution binocular eye tracker using two USB3 infrared monochrome cameras having 640x480 pixel resolution, and sampling images at 400 Hz (TheImagingSource, Model DMK33UX174)	Microsaccades	Stimuli: small yellow target on a black screen. Distance 50 cm with chin rest.	Ivanchenko et al.
2019	Combining visual sensory functions and visuospatial orienting functions in children with visual pathology	119 children with visual impairment (age 1 to 12 years)	Tobii T60XL (Tobii Corporation, Danderyd, Sweden)	Reaction time to fixation Fixation duration Gaze fixation	Longitudinal study. Paradigm: Preferential looking. Stimuli: various visual stimuli, each was placed in one of four monitor quadrants. Statistical analysis: Matlab	Kooiker et al.
2019	Study Presaccadic motion integration drives a predictive postsaccadic following response	8 participants (18-22 years old) with normal vision	Infrared eye tracker (USB-220, Arrington Research, Scottsdale, AZ)	Eye position	Distance: 95.5 cm Stimuli: four equally eccentric motion dots.	Kwon et al.
2019	Test directly whether pursuit catch-up saccades and fixational micro-saccades exhibit the same temporal pattern of task-related bursts and subsidence	4 subjects	Eyelink 1000 1000 Hz	Fixations Pursuit saccades Saccades amplitude	Stimuli: created in Matlab. Discrimination task, 15-character alphanumeric array paradigm, fixation, and pursuit task	Badler et al.
2019	Propose and evaluate a new approach to paracentral VF assessment that combines an inexpensive eye-tracker with a portable tablet computer (“Eyecatcher”)	24 eyes from 12 glaucoma patients 12 eyes from 6 controls	Eyecatcher Tobii EyeX eye-tracker (Tobii Technology, Stockholm, Sweden) 50 Hz	fixations	Distance: 50 cm Stimuli: programmed in C# and R. White Goldmann III (0.43°) circular spots, presented at a fixed intensity of 300 cd/m2	Jones et al.

			Without chinrest			
2019	Propose a compensatory visual-field training using game-like dynamic scenes presented by a head-mounted display eye tracker (HMD-ET)	10 subjects with normal or corrected to normal vision	HMD-ET. 240 Hz	Eye fixations during a compensatory visual fiel training	E-T permits to reveal differences in patterns of visual exploration between people	Hotta et al.
2019	Determine the latencies of orienting responses during a preferential looking task in children with normal vision and in children with visual impairments	Eighty-eight children (9.61.8 years) with normal vision (NV), 15 children(9.01.6 years) with cerebral visual impairment (CVI), and 19 children(9.02.4 years) with visual impairment due to congenital or acquired disorders of the eye without additional impairments	Stereoscopic eye tracking system with two USB 3.0 cameras and two infrared lights. 300 Hz	Gaze position Saccades Fixations Fixation time	Paradigm: preferential looking. Stimuli: 2 × 2 grid, with three uniform grey fields and one target field consisting of a black-and-white square wave grating. E-T: provides objective detection measures	Barsingerhorn et al.
2019	Explore the problems associated with calibration and propose a method that secures a repeatable and reliable gaze estimation.	8 patients with nystagmus	EyeLink 1000 Plus. 1000 Hz	Calibration on targets		Rosengren et al.
2019	Confirm that visual crowding resulted in decreased performance and prolonged saccadic reaction time (SRT) in crowding trials compared to reference trials	25 subjects (age range 19-26 years)	Tobii T60XL eye tracker (Tobii Corporation, Sweden)	Binocular eye movements	Paradigm: visual crowding Distance: 57 cm. Stimuli: 5 charts with different fixation stimulus, color, letter, contrast, spatial frequency and shape. Statistical analysis: Matlab Pilot study was applied first.	Pel et al.
2019	Describe the functional and activity-based outcomes from an intense vision therapy program targeting visual function issues, including issues related to peripheral visual field loss, following stroke	3 females subjects (29, 29 62 years old)	SMI eye tracker 250 Hz	Fixation, saccades, visual search and reading		Axelsson et al.

2019	Assess the visual function, reading performance, and compensatory head posture (CHP) in schoolchildren with infantile nystagmus	18 participants aged between 13 to 18 years old were divided into spectacle (n=9) and null zone group (n=9	Tobii TX300 eye tracker	Time of reading	Sample size: Cochran`s formula. Participants were recruited randomly.	Fadzil et al.
2019	Development of a virtual reality (VR) video game platform, guided through Fuzzy Logic, targeting casualties with amblyopia and convergence insufficiency conditions	Age range 9-18 years	FOVE (head-mounted display) 100 Hz.	Eye positions	Stimuli: games of Vision Labs	Esfahlani et al
2019	Study how restricting visual acuity of normally sighted subjects would affect visual search and navigation in a real-world environment, and how their performance would compare to subjects with naturally occurring low vision.	Experiment 1. 8 normally sighted subjects (mean age 23) Experiment 2. 8 low vision subjects (mean age 55 years)	Tobii Glasses 1 mobile head-mounted eye tracker (Tobii Technology, Inc., Falls Church, VA., https://www.tobii.com/)	Fixation	Two experiments: looking for objects and comparison between acuity-restricted normally sigthed subjects and low vision people. Statistical analysis: ANOVA	Freedman et al.
2019	Study task-driven visual exploration at the foveal scale	31 emmetropic human (age range 18-25 years)	Generation 6 Dual Purkinje Image (DPI) eye tracker (Fourward Technologies)	Microsaccades Drifts Saccades	Stimuli: images of faces taken from online databases	Shelchkova et al.
2019	Investigate whether and how visual acuity at selected foveal locations changes before the onset of microsaccades	6 emmetropic subjects (5 females, age range 19-29 years)	Generation 6 Dual Purkinje Image (DPI) eye tracker (Fourward Technologies)	Saccades Microsaccades		Shelchkova & Poletti
2019	Study smooth pursuit of a modally completed images	10 participants with AMD (mean age 77.9 +/- 7.8) 12 control participants (mean age 44.5 +/- 20.5)	Eyelink 1000 (SR Research)	Saccadic eye movements	Stimuli: smooth pursuit	González et al.
2019	Investigate human interceptive saccades and pursuit responses to moving targets defined by high and low luminance contrast or by chromatic contrast only (isoluminance)	11 subjects (8 females, mean age 24.7 +/- 3.2 years)	EyeLink 1000 Plus (SR Research Ltd., Mississauga, Canada) 1000 Hz	Eye position Saccades		Goettker et al.

2019	Study how rapidly infants detect human faces in complex naturalistic visual scenes	241 infants (3 months -12 months)	Eyelink 1000+ (SR Research, Ontario) 500 Hz	Fixations Saccades	Stimuli: Visual Saliency. P Photographs of complex indoor and outdoor scenes presented with Experiment Builder and data was extracted with Data Viewer. Distance: 60 cm Statistical analysis: Matlab	Kelly et al.
2019	Study eye Movements of Drivers with Glaucoma on a Visual Recognition Slide Test	31 older drivers with glaucoma (mean age 71.7 +/- 6.3 years) 25 age matched with normal vision (mean age 71.1 +/- 6.6. years)	Tobii TX300 (Tobii Technology, Danderyd ,Sweden)	Total fixations Number of fixations per second Average fixation duration Average saccades amplitude Horizontal and vertical variance	Stimuli: DriveSafe test. Statistical analysys: R was used. Mann-Whitney U test, chi square test	Lee et al.
2018	Examine the characteristics of small saccades by means of two of the most established high-resolution eye-tracking techniques available	7 subjects Observers 4 subjects (age range 30-70)	Binocular Dual Purkinje Image eye tracker Revolving Field Monitor, a specially designed eye-coil apparatus Eyelink 1000+ (SR Research, Ontario) 500 Hz	Fixations Small saccades Microsaccades Saccades amplitude	Stimuli:small crosses (27′ × 2′ bars) displayed on a CRT monitor at a refresh rate of 200 Hz Head-rest Distance: 50-60 cm	Fang et al
2018	Characterize how acuity restriction affects gaze behavior while subjects with normal and low vision searched for and identified targets during navigation	8 low vision subjects 8 normally sighted controls	Tobii head-mounted eye tracking system	Gaze transitions Gaze direction	Stimuli: look for objects Statistical analysis: correlation tests	Freedman et al.

2018	To investigate whether glaucoma produces measurable changes in eye movements	50 patients with glaucoma and asymmetric vision loss	Eyelink 1000 (SR Research Ltd., ON, Canada) 1000 Hz	Saccadic reversal rate (SRR), saccade amplitude, fixation counts, fixation duration, and spread of fixation locations	Distance: 60 cm Chin rest Stimuli: viewed monocularly displayed duration between 3 and 5 seconds. 39 color images and 81 grayscale images, natural scenes. Statistical analysis: Wilcoxon`s test. Multiple regression analysis.R was used.	Asfaw, D. , et al.
2018	Investigate the effects of a specially designed combat sports (CS) training program on the visuomotor performance levels of children	Children aged 9-12 years	EyeLink 1000 (SR Research Ltd., ON, Canada) With chinrest	Saccades Eye response time	Stimuli: hit or visually track. Statistical analysis: comparative statistic, descriptive statistic	Ju et al.
2018	Compare the performance of an automated and objective method to measure near heterophoria using an eye-tracker with two conventional methods: the cover-uncover test and the modified Thorington test	30 non-presbyopic adults (15 females, mean ae 27.9 +/-4.6 years)	EyeLink100 250 Hz	Eye position Fixation	Stimuli: fixation stimulus consisted of an empty black circle of 1.6˚.The inner white region subtended an angle of 0.9˚with a 20/50(0.21˚)Snellen E letter at the center to favor fine fixation. E-T benefits: provides objective and more repeatable measures, should be the new gold standard to measure heterophoria.	Mestre et al.
2018	Determine the optimal gain (stimulus/eye motion ratio) that corresponds to maximum performance in an orientation-discrimination task performed at the fovea	7 human subjects with normal or corrected to normal vision (ages 18-35)	Tracking Scanning Laser Ophthalmoscope (TSLO; Shehhy et al., 2012) Eye movement sampling rate of 960 Hz	Eye movements		Agaoglu, M. et al.
2018	Investigate the impact of training with action video games on balance function in older adults using a randomized controlled trial design.	146 healthy adults (age over 60)		Saccadic eye movements Pursuit eye movements	Stimuli: 20 hours of cartoon-like action video-game training. Pretest, training, postest	Cheong et al.

				Fixations		
2018	Test if a scanning mode utilizing eye movements increases visual stability and reduces head movements in Argus II users	8 blind individuals	Eye Tracking Glasses 2.0 (ETG 2.0; SensoMotoric Instruments, Teltow, Germany) 60 Hz	Location of the target	Stimuli: target that had to be touched. E-T benefits: Integrating an eye tracker into the Argus II is feasible, reduces head movements in a seated localization task, and improves pointing precision.	Caspi et al.
2018	Examine whether the stability of steady fixation was different in individuals with corrected myopia and corrected hyperopia during a fixation task.	10 healthy subjects (mean age 24.2 +/- 2.6 years)	Eyelink 1000. 1000 Hz	Fixation stability	Monocularly Vertical and horizontal eye position BCEA Statistical analysis: descriptive statistic	Coletta et al.
2018	Evaluate differences in eye movements during reading in strabismic children and in non-strabismic age-matched children, and to evaluate the potential effect of strabismus surgery on eye movement performance.	9 Strabismic children (age range 11- 15 years)	Mobile T2 (SuriCog, France) 300 Hz	Fixations Fixations duration	Stimuli: reading task with both eyes and monocularly.	Perrin-Fievez et al.
2018	Develop a tracking test to record participants' eye-movements while we simulated different gaze-contingent Visual Field Defects.	50 healthy participants and 1 glaucoma patient	Eyelink 1000 (SR-Research, Kanata,Ontario, Canada)	Saccadic pursuit Smooth pursuit	Stimuli: Gaussian luminance blob (FWHM = 0.5 degrees of visual angle) moving in a2D random-walk path.	Grillini et al.
2018	Automatic Detection of Preferred Retinal Locus (PRL) for Low Vision Rehabilitation using Oculometrics Analysis	9 participants with normal vision	Tobii Pro TX-300 (Tobii AB) 300 Hz	Fixations	Statistical analysis: Median Absolute Deviation. E-T benefits: it allows an automated PRL detection system.	Yow et al.
2018	Develop a comprehensive protocol for suction stability management during small incision lenticule extraction (SMILE)	-	-	Fixation light tracking, Bell's reflex, saccades, oscillations, nociceptive reflex movement, false	Stimuli: video recording during incision.	Reinstein et al.

				suction, and nystagmus		
2018	Characterize the gaze stability of young infants, adult participants and 4- to 10-week-old infants	22 typically developing, full-term infants (4-10 weeks) and 13 adults	EyeLink 1000 (SR Research, Ottawa, Canada) 250 Hz	Fixations Stability of gaze position First visit	Stimuli: Random-noise patterns were presented on a rear-projection screen that preserved circular polarization. Monocularly. Psychophysics Toolbox Statistical analysis: Shapiro-Wilks test, Welch`s test	Seemiller & Candy.
2018	Use standard automated perimetry to compare fixation variability among the dominant eye fixation, non-dominant eye fixation, and binocular fixation conditions	35 healthy eyes of 35 subjects	Tobii glass II (TobiiTechnology, Stockholm, Sweden) 50 Hz	Fixation variability	Cross-sectional study BCEA Statistical analysis: R was used, paired t-test, Pearson`s correlation, Bonferroni test	Hirasawa et al.
2018	Explore the relationship between eye movements performance and Visual Acuity, central Visual Field, as well as AMD features	187 subjects	Tobii TX300	Gaze points	Cross-sectional study. Monocularly. Statistical análisis: Student`s t test. Linear regression analysis. Significance level 0.05 E-T benefits: Tracking eye gaze can assist visual function assessment in AMD.	Laude et al.
2018	Describe an efficient new tool for measuring contrast sensitivity, Curveball, and empirically validate it with a sample of healthy adults	35 healthy adults (19 women, 16 men; mean age 38.6615.8) with normal or corrected-to-normal	Tobii 4C eye tracker (Tobii Technology, Stockholm, Sweden	Smooth tracking	Stimuli: curve ball task	Mooney et al.
2018	Assess the extent of visual search deficits in amblyopia using feature and conjunction search tasks.	10 participants with anisometropic, strabismic, or mixed amblyopia	EyeLink 1000 remote eye tracker (SR Research, Ottawa, Canada	Fixations Saccades	Distance: 100 cm Chinrest Stimuli run with Psychotoolbox with Matlab. Four experiments: contrast threshold estimation, target separation estimation, feature search, conjunction search.	Tsirlin et al.

					Statistical analysis: ANOVA, Welch`s test, alpha 0.05.	
2018	Propose a new (micro)saccade detection method, based on an unsupervised clustering approach, that can effectively separate fixational microsaccades from high-frequency recording noise	14 subjects (age range 69-81 years)	The EyeLink 1000 (SR Research Ltd., Ontario, Canada)	Microsaccades	Distance: 57 cm Monocularly	Sheynikhovich et al.
2018	Investigate how peoples' eye movements adapt and optimize in response to a simulated scotoma in an object recognition task using a gaze-contingent display.	10 participants (4 males, mean age=26.2y) with normal visual acuity	Tobii PRO TX-300	Eye movements Saccades Fixations	Stimuli, indicate wether a randomly placed object was either a non-sense object or a known one.120 trials per session. Distance: 60 cm Chinrest Training with 9 sessions, two per weel.	Ryu & Wallraven
2017	Develop a novel dichoptic optokinetic nystagmus (OKN) paradigm and investigate its effectiveness in objectively quantifying the interocular suppression in subjects with monocular amblyopia	8 amblyopia subjects (amblyopia group) and 8 age- and sex-matched normal subjects (control group)	EyeLink (SR-Research, Ontario,Canada)	Eye movements Blinks	Distance: 57 cm Statistical analysis: Correlation. Spearman`s correlation.	Wen et al.
2018	Measure cone-sampling-limited acuity at sub-foveal intervals and measure the functional role of microsaccades (MS) when presented with at-threshold stimuli at varying sub-foveal distances from the preferred fixation locus (PRL).	3 males and 3 females (ages 25-29 years) with no known visual issues	Adaptive optics scanning laser ophthalmoscope (AOSLO)	Fixational eye movements	Stimuli: tumbling-E	Ratnam et al.
2018	Determine the ability of Saccadic Vector Optokinetic Perimetry (SVOP) to detect and characterize visual field defects in children with brain tumors using eye-tracking technology	16 patients (mean age 7.2 years, 7 male)	IS-1 eye tracker X50 eye tracker	Eye gaze Fixations	Stimuli. Fixation tasks	Murray et al.

				Direction and amplitude of each saccade		
2018	Evaluate binocular eye movements to targets when central vision is compromised. Study if binocular vision deficits may be underestimated by monocular vision tests and identify a method that can be used to select a PRL based on binocular contrast summation	10 participants (Mean age 24.1 years)	Eyelink II (SR Research, Ottawa, Canada) 500 Hz	Location of each eye	Stimuli: generated and presented with Matlab. Full alphabet Distance: 50 cm Statistical analysis: parametric analysis, R was used. Bonferroni test for multiple comparisons.	Alberti & Bex.
2018	Study the miniature eye movement for seeing fine spatial details	7 subjects (range age 18-35 years) with normal or corrected vision	Tracking Scanning Laser Ophthalmoscope (TSLO; Shehy et al., 2012)	Fixaional eye movements	Stimuli: task was to report the orientation of a sinusoidal grating from vertical. Dark room,	Ağaoğlu et al.
2017	Investigate whether the normal aging process influences the ability to adapt disparity vergence and phoria	49 healthy subjects (Ages 20-70 years)	Video-based ISCAN eye movement monitor LabVIEW™ program, VisualEyes, with 12-bit digital acquisition hardware card 500Hz	Eye movements, tracking both eyes simultaneously and independently Peak velocity	Distance: 40 cm Chin rest Statistical analysis: Matlab, ANOVA, linear regression analysis.Pearson correlation.	Alvarez, T. et al.
2017	Assess if adaptations improve binocular contrast sensitivity in the peripheral visual field	6 subjects normally sighted obervers	Eyelink II 100 Hz	Fixation	Stimuli: 26AFC task. Letters were positions 2º in the lower visual field.	Alberti & Bex
2017	Characterize saccadic rhythmicity, and examine whether it is consistent with an autonomous oscillatory generator or with a self-paced generation	36 students with normal vision First experiment: 12 subjects, 7 females (mean age 25.9 +/-2.3 years)	Eyelink 1000 Plus SR Research, Canada 1000 Hz	Saccades Microsaccades	Stimuli: An 11 minutes long nature movie clip with sound. 3 experiments. Distance: 57 cm	Amit, R., et al.

		Second experiment:11 subjects, 6 females (mean age 26-1 +/- 2.7 years) Third experiment: 12 subjects, 7 females (mean age 26.1 +/- 2.7 years)				
2017	Perform usability testing of a binocular optical coherence tomography(OCT) prototype to predict its function in a clinical setting.	45 participants with chronic eye disease (mean age 62.7 years) 15 healthy controls (mean age 5 years)	Optical coherence tomography (OCT)	Fixations	Monocularly. Stimuli: fixation target in primary position and 8 positions of gaze 4º from center.	Chopra et al.
2017	Determine if microsaccades are altered in hemianopia; how altered microsaccade features correlate with visual performances; and how their direction relates to visual field defect topography.	14 hemianopic stroke patients (13 male, mean age 59) 14 healthy controls (11 male, mean age 60)	EyeLink-1000 system (SRResearch, Ontario, Canada) 500 Hz	Microsaccades (rate, amplitude, and velocity)	Case-control study Stimuli: fixation dot in 41 trials lasting 7 secons each one	Gao & Sabel.
2017	Explore the effect of latency for foveated rendering in Virtual Reality (VR) applications and evaluate the detectability of visual artifacts for three techniques capable of generating foveated images and for three different radii of the high-quality foveal region	First experiment: 9 subjects Second experiment: 2 subjects	SMI eye tracker 250 Hz Tobii TX300 eye and head tracker 300 Hz	Metrics: head translation, head rotation, frequency of saccades, saccades amplitudes	Stimuli: classroom scene	Albert, R., et al.
2017	Investigates whether the induced PRLis transferred to important visual tasks in daily life, namely pursuit eye movements, signage reading, and text reading	50 subjects. 10 females (mean age 26.6 years)	Eyelink 1000 Plus. 1000 Hz	Saccades velocity Pursuit eye movements	Simulate scotoma Chinrest Distance: 62 cm 3 sessions: saccades task, pursuit task, signage reading, text reading.	Barraza et al

2017	Evaluate whether the eye tracking system (ETS) improved the reproducibility of a single circle peripapillary retinal nerve fiber layer (RNFL) measurement acquired with spectral-domain optical coherence tomography (OCT)	205 people 100 healthy individuals 105 patients with open-angle glaucoma	Spectralis self-acting eye-tracking (eye tracker)	Eye movements	Statistical analysis: correlation coefficient, coefficient of variation, test-retest variability.	Abadia, B,. et al.
2017	Investigate the impact of accommodation, convergence, and proximity on the pupillary diameter.	12 subjects (6 female, age range 21-28) Experiment 2: 9 subjects (2 female, mean age 25 years)	EyeLink 1000 with Experiment Builder (V1.10.165, SR Research Ltd., Mississauga, Ontario, Canada)	Pupil size Pupil response Vergence eye movements	Chin rest Distance: 25 cm and 4 m Stimuli: Landolt rings as targets Statistical analysis: ANOVA, SPSS, one sample t test	Feil et al.
2017	Characterize eye movements made by patients with intermittent exotropia when fusion loss occurs spontaneously and compare them with those induced by covering 1 eye and with strategies used to recover fusion	13 patients with typical findings of intermittent exotropia who experienced a frequent spontaneous loss of fusion (6 male, range 11-61 years)	Infrared video-based eye tracker (iView X, SensoMotoric Instruments), sampling at 60 Hz	Eye position Peak velocity	Calibrated monocularly. Chinrest Accepted ± 1º accuracy Distance: 57 cm Stimuli: central target and peripheral target in random location. Data analysis: Wilcoxon rank sum test	Economides & Adams
2017	Investigate the relation between the placement of sustained attention and the location of a developed PRL using simulations of central scotoma	30 subjects (4 males, mean age 25.3 years)	Eyelink 1000. 100 Hz	Fixation :stability, eccentric Saccades	Stimuli: Matlab, Psychotoolbox and Eyelink toolbox were used. Target was located along different meridians, 8 locations, 1 second each target. Scotoma was simulated. Chinrest Distance: 66.6cm Statistical analysis: BCEA,	Barraza et al.

2017	Determine if the deviation angle changes in subjects with intermittent exotropia they alternate fixation between the right and left eye in primary gaze	37 subjects with intermittent exotropia	iViewX (SensoMotoric Instruments, Teltow, Germany)	Eye positions	Calibrated monocularly Chinrest Accepted ± 1º accuracy Distance: 57 cm Stimuli: central target and peripheral target in random location, people had to saccade to the peripheral target Data analysis: blinks were excised, mean position and SD. Wilcoxon rank sum test.	Adams et al.
2017	Assess whether such adaptations improve binocular contrast sensitivity in the peripheral visual field.	6 subjects with normally sighted	Eyelink II 1000 Hz	Fixation control	Stimuli: letters were positioned 2º in the lower visual field. Controlled with nVidia 3D glasses	Concetta, A. & Bex, P.
2017	Study if Binocular Fixation Reduces Fixational Eye Movements in the Worst Eye of Patients with Center-Involving Diabetic Macular Edema	57 eyes from 29 diabetic patients	iView X™ video-based eye tracker	Monocular and binocular fixations Fixation stability (BCEA) Minimum saccade velocity Fixational saccades	Cross-sectional study Chinrest and foreheadrest Stimuli: black cross was presented for 40s. Statistical analysis: student paired t test, Bonferroni multiple comparison tests, simple linear regression to correlations	Jakobsen et al.
2017	Study the Impact of eye tracking technology on OCT-Angiography imaging in patients with age-related macular degeneration	30 eyes of 30 AMD patients (21 females, aged78.97 ± 9.7 years, range 58–94 years)	OCT-system (AngioVue, RTVue XR Avanti SD-OCT, Optovue,Fremont, CA, USA)	Fixations Blimks	Statistical analysis: Kolmogorov-Smirnov. Non-parametric tests. Coefficients of variation. Spearman r test. Wilcoxon test (paired) and Mann-Whitney test (unpaired). Statistical significance at 0.05 E-T benefits: improves image quality in OCT-A	Lauermann et al.
2017	Assess the eye movement patterns and visual predictors of performance on a	30 older drivers with glaucoma (71±7 years) and 25 age-matched controls (72±7 years).	Tobii TX300eye-tracker (Tobii Technology, Danderyd, Sweden),	Response time Smaller saccades	Stimuli: Hazard Perception Test	Lee et al.

	laboratory-based hazard detection task in older drivers with glaucoma.			First fixations	Statistical analysis: SPSS, level of significance 0.05. Independent sample t-test. Linear mixed-effects models.	
2017	Develop a method can be used to detect and characterize sensorimotor deficits associated with TBI	34 Traumatic Brain Injury subjects	Comprehensive Oculometric Be-havioral Response Assessment (COBRA)	Pursuit latency Pursuit acceleration Saccades amplitude Smooth tracking	Stimuli: 15 minutes eye movement tracking, 180 trials. Comprehensive Oculometric Behavioral Assessment (COBRA) Chinrest	Liston & Stone.
2017	Study if patients with AMD would be able to track both the completed and visible pursuit stimuli by using peripheral retinal information.	4 patients with AMD and 11 controls with normal vision	Tobii TX300	Smooth pursuit Mean peak velocity gain Saccade frequency Sacadde amplitude		Liu et al.
2017	Detect AMD caused vision impairment from gaze data	74 eyes of 57 Patients with AMD	Tobii TX300 Nidek Microperimetry	Fixations Smooth pursuit	Monocularly Distance. 60 cm	Liu et al.
2017	Analyze the differences between deviations of both eyes and the displacement of one single eye during the measurement of horizontal phoria in the cover test	9 subjects (mean age 22.3 ± 3.5 years), normal or corrected-to-normal visual acuity and a horizontal phoria greater than 1 PD	Eye-tracker embedded in the stereoscopic virtual reality system EVA (Eye and Vision Analyzer, Davalor Salud, Spain)	Eye position	Distance: 40 cm Stimuli: Fixated an stimulus during 2 cycles: binocular vision, right eye occlusion, binocular vision, left eye occlusion. Statistical analysis: dependent t-test, means and SD E-T benefits: the possibility of registering both eyes`s movements.	Mestre et al.
2017	Investigate the relationship between silent reading performance and visual	50 glaucoma patients (mean age,52.2 +/-11.4years)and 20 normal controls(mean age,46.9 +/-17.2 years)	Tobii TX300 (Tobii Technology Danderyd, Sweeden) 300 Hz	Reading duration	Prospective cross-sectional study	Murata et al.

	field defects in patients with glaucoma using an eye tracking			Mean fixation duration. Total visit duration Fixation count	Stimuli: 3 articles composed of 607-612 characters with 12-13 lines per paragraph Distance: 60 cm Environmental conditions were controlled. Statistical analysis: SPSS, Mann-Whitney U test, chi-square test, student`s t test. Spearman`s rank correlation coefficient.	
2017	Evaluate threshold saccadic vector optokinetic perimetry (SVOP) and compared results to standard automated perimetry (SAP)	162 subjects (103 with glaucoma and 59 healthy subjects)	Tobii IS-1 model (Tobii Technology, Stockholm, Sweden)	Eye gaze responses Fixation Eye location	Cross-sectional study Stimuli: a fixation target Distance: 55 cm Statistical analysis: Shapiro-Wilk tests, Wilcoxon rank-sum test, ANOVA. SPSS. Level of significance 0.05.	Murray et al.
2017	Examine the relation between dynamic visual acuity (DVA) and the kinematics of smooth pursuit and saccadic eye movements	23 males (mean age19.5 +/- 1.2 years)	Eyelink 1000 Desktop Mount (SR Research Ltd., Ottawa, ON, Canada) 1000Hz	Smooth pursuit Eye position Velocity Saccades	Stimuli: computer-based dynamic object task, black Landolt-C rings. Distance: 71.5 cm Statistical analysis: ANOVA, bivariate correlation coefficients. Level of significance 0.05. SPSS	Palidis et al.
2017	Investigate reading rates in age-matched normal and early to intermediate AMD patients with similar acuity.	21 subjects (11 AMD, age 78.4 +/- 7.49) (1o controls, ae 75.2 +/-5.75)	Tobii TX300 Eye Tracker	Saccades, fixations, regressions, and blinks	Stimuli: Wilkins reading test Distance: 60 cm	Ridder et al.
2017	Investigate potential differences in comprehension, brain wave activity, and eye movements, when people read texts with or without blue-filtering lenses	34 participants (24 males, students, mean age=23.5y) with normal visual acuity	Tobii XL120, 120Hz	Eye movements Saccades	Stimuli: 6 texts with different topics displayed for 120 s. Statistical analysis: non-parametric tests. Matlab	Ryu & Wallraven

2017	Compare different metrics and acquisition modes of fixation stability as a new visual function biomarker in patients with ABCA 4-related Stargardt disease	235 patients	Nidek MP-1 microperimeter (Navis, Nidek Technologies, Italy)	Fixation stability(BCEA) Fixations	Stimuli: a fixation target Monocularly Statistical analysis: correlation tests	Schönbach et al.
2017	Study monocular and Binocular Smooth Pursuit in Central Field Loss	7 participants with central field loss (ages: 52–91, 4 males) and 4 controls (ages: 70–84, 1 male)	Eyelink 1000	Smooth pursuit	Distance: 1m Chinrest Stimuli: 90 trials of the same viewing condition: binocular, monocular left and monocular right. White target that appeared at one of six locations Statistical analysis: linear mixed-effects models. Correlation coefficients.	Shanidze et al.
2017	Explore whether character identification and image localization could be achieved through direct multiple-electrode stimulation with a suprachoroidal retinal prosthesis.	-	External infrared eye-tracking camera (Arrington Research,Inc., Scottsdale, AZ, USA	Eye movements Gaze location	Stimuli: static imagen localization and dynamic imagen localization. Statistical analysis: ANOVA. E-T benefist: analyze the impact of eye movements on a performance in a task.	Shivdasani et al.
2017	Examine whether viewing distance affects fixation stability during binocular and monocular viewing	30 patients with AMD	video-based eye-tracker (Series 2020; El-Mar, Inc., Toronto, ON, Canada) 120 Hz	Fixations BCEA Blinks Saccades	One experimental session Chinrest Distances: 40 cm, 1 m and 6m Monocularly and binocularly Statistical analysis: Shapiro-Wilk test, ANOVA	Tarita et al.
2017	How crowding and collisions affect gaze anchoring and dual-task performance	14 subjects (7 female, age range 20.4 +/- 1.1 years)	Monocular eye-tracking system, EyeSeeCam, 220 Hz (ESC; EyeSeeTech GmbH, Furstenfeldbruck, Germany)	Paradigm: Multiple-object tracking.	Stimuli: Matlab, 10 stationary squares. 20 test blocks grouped 12 test trials. 2 sessions	Vater et al.

				Vertical and horizontal rotations of the right eye	Statistical analysis: ANOVA. Level of significance p=0.05	
2017	Determine the extent to which eye movements in children with delayed reading skills are different from those obtained from children with good/average reading skills in non-reading-related tasks	120 children without delayed reading skills and 43 children with delayed reading skills	Tobii TX300 eye tracker.	Fixation stability. Saccadic main sequences, and the number and amplitude of the saccades during fixation	Distance: 65 cm Stimuli: animal cartoons that appeared in 4 positions or in the center of the screen Statistical analysis: Matlba, SPSS, Shapiro-Wilk tests, parametric and no parametric tests, ANOVA, chi-square test. Mann-Whitney test.	Vinuela et al.
2017	Automatic Visual Impairment Detection System for Age-related Eye Diseases through Gaze Analysis	69subjects with clinically diagnosed AMD	Tobii Pro TX-300 (Tobii AB) 300 Hz	Gaze tracking	Stimuli: impulse stimulus response test and pursuit stimulus response. Monocularly	Yow et al.