Journal of Eye Movement Research
9(7):3, 1-8

Optically induced refractive errors reduces fixation stability but saccade latency remains stable

Gro Horgen Vikesdal
University College of Southeast Norway
Norwegian University of Life Sciences

Trine Langaas
University College of Southeast Norway

The purpose of this study was to investigate the effect of optically induced refractive errors on saccade latency and fixation stability. Sixteen healthy, young adults (two males), with normal visual acuity and normal accommodation, performed a saccade task and a fixation task wearing a range of contact lenses (from +3.00 to -5.00 diopters) which induced visual blur and accommodation. The results showed that mean (± standard error) saccade latency was 207 (± 5) milliseconds (ms) and remained stable with both visual blur and accommodation, whereas mean (± standard error) fixation stability was logBCEA 2.48 (± 0.03) (arcmin²) and declined by about 0.09 logBCEA with both visual blur and accommodation.

In healthy adults with normal vision, results indicate that recording of saccade latency can be completed accurately regardless of the moderate refractive errors induced in this study. Fixation stability, on the other hand, degrades slightly with blur and with accommodation.

Keywords: eye movement, eye tracking, saccades, gaze, fixation stability, refractive error, visual acuity, blur, accommodation

Introduction

Saccade latency refers to the reaction time of a visually guided saccade; it is the time between the appearance of a visual target and the onset of a directional eye movement. In general, the latency of visually guided saccades in healthy adults is typically around 200 ms with a standard deviation of about 10% (Holmqvist et al., 2011). Fixation stability can refer to a period of oculomotor stillness, or it can imply perceptual input and processing. Fixation stability is often thought a of as a reflection of attention ability (Rommelse, Van der Stigchel, & Sergeant, 2008).

Saccade latency is a prevalent measurement in patient populations that might have compromised vision and poor accommodation, yet not many studies have investigated the relationship between saccade latency and vision. Studies normally report visual acuity but not necessarily at the relevant experimental testing distance (Bednarek, Tarnowski, & Grabowska, 2006; Biscaldi, Gezeck, & Stuhr, 1998; Yang, Bucci, & Kapoula, 2002). Saccade latency has been found to be a reliable measure with good internal consistency, and is considered trait-like in adults (Ettinger et al., 2003; Vikesdal & Langaas, 2016). However, one study has shown that induced blur does not affect saccade latency but that subjects with amblyopia show increased saccade latency compared to control subjects (Niechwiej-Szwedo et al., 2012). To our knowledge, no previous studies have induced accommodative response in saccade latency tasks.

The relationship between fixation and vision has been previously investigated but with conflicting results. Sev-

Received July 12, 2016; Published October 28, 2016.
Citation: Vikesdal, G. & Langaas, T. (2016). Optically induced refractive errors reduces fixation stability but saccade latency remains stable. *Journal of Eye Movement Research*, 9(7):3, 1-8.
Digital Object Identifier: 10.16910/jemr.9.7.3
ISSN: 1995-8692

eral studies have looked at the effect of blur on fixation accuracy. One such study found that fixation stability decreased slightly with optical blur ≥ 2.0 D (Ukwade & Bedell, 1993). In contrast, another study found that insertion of +5.0 D contact lenses reduced gaze errors (R. M. Steinman, Pizlo, Forofonova, & Epelboim, 2003). Another study found that eyes with poor visual acuity due to amblyopia exhibit less stable fixation than their fellow eyes and that when the good eye was covered and the amblyopic eye had the visual input, the good eye also exhibited poor fixation stability (Gonzalez, Wong, Niechwiej-Szwedo, Tarita-Nistor, & Steinbach, 2012). The finding of reduced fixation stability with degraded visual input supports the idea that visual feedback is important for the stabilization of gaze; often referred to as a “closed-loop” neural control system (Otero-Millan, Macknik, & Martinez-Conde, 2014). Steinman et al presented a note in 1968 claiming that the relaxation of accommodation (induced by the use of a cycloplegic agent) improved fixation stability by decreasing the number of microsaccades (Robert M. Steinman, Skavenski, & Sansbury, 1969). Following that analogy, increasing accommodation should decrease fixation stability. To our knowledge, there have been no studies looking at the effect of increased accommodation on fixation stability.

It has been suggested that the increased number of microsaccades observed in strabismic amblyopes while maintaining fixation, result in increased saccade latency (McKee, Levi, Schor, & Movshon, 2016). If this hypothesis is correct, increased fixation instability should lead to saccadic delay. We have previously shown that both saccade latency and fixation stability (indexed by log-BCEA) have good internal consistency, reliability and repeatability, which are not influenced by sighting dominance or contact lens wear (Vikesdal & Langaas, 2016). By investigating the effect of induced optical blur and accommodative response in visually-normal adults we wanted to explore the relationship between visual acuity, accommodation and eye movement control. Our intention was to clarify the importance to detect uncorrected refractive errors in studies of eye movement control. In line with previous findings, we hypothesized that both decreased visual acuity and increased accommodative response would lead to a more unstable fixation and saccadic delay.

Materials and methods

Subjects

Sixteen healthy adult subjects (two males), aged between 21 and 39 years (mean age 29.5 ± 7.3 years) were recruited from the student and employee populations at the University College of Southeast Norway. Subjects underwent a thorough optometric examination prior to participation which included ocular refraction, near point of accommodation (by RAF rule), positive relative accommodation, negative relative accommodation, accommodative facility, heterophoria distance and near, fixation disparity, near point of convergence, vergence facility, positive fusional reserves distance and near, negative fusional reserves distance and near. Inclusion criteria were normal visual acuity with best refraction within -6.00 D to +4.00 D sphere and cylinder < 0.75 D as well as phorias, vergence and accommodation measures within one standard deviation of expected values for age (Scheiman & Wick, 2002). Subjects were healthy and did not have a history of any psychiatric or developmental disorder. All subjects gave informed consent prior to inclusion in the study. The experiment was conducted in accordance with the Declaration of Helsinki (WMA, 2013).

Apparatus and stimuli

During the experiment the subject sat in a firmly mounted chair 100 cm from a computer screen, with the subject’s eyes in line with the center of the screen. A chin- and forehead rest was used in order to minimize head movements. A video-based eye-tracking system, the IScan ETL-300, recorded the vertical and horizontal position of the dominant eye with a sampling frequency of 120 Hz and an accuracy of 0.3° (ISCAN, 2003). The eyetracker uses corneal reflection and the center of the pupil to obtain eye position, and precision for this setup was 0.161° (RMS). Further details of the instrumental setup are described elsewere (Vikesdal & Langaas, 2016). A calibration procedure was carried out prior to each experimental session, with five calibration points, one central point and four points placed in the corners of the screen. Eye position data, with accompanying time stamps, were exported to Excel for post-experimental analysis. Eye movements were recorded with both eyes open to allow both accommodation and vergence to occur, as in natural viewing. Subjects were instructed to focus on the stimulus as much as possible; as the stimulus was small, it would be expected to incite accommodative effort. The stimulus consisted of a bright yellow dot 0.2° in diameter presented on a dark grey background on a fast phosphor monitor; the contrast level was 92%. The room was dimly illuminated and the stimulus was easily visible in all experiment conditions.

Procedure

The experiment comprised one saccade task and one fixation task. Subjects performed the experiment whilst wearing various sets of daily disposable soft contact lenses (material: hilafilcon B; curvature: 8.6 mm; diameter: 14.2 mm). Optical power was added to each subjects' ocular refraction individually, plus to induce blur and minus to induce accommodation. Subjects were tested wearing 6 different sets of contact lenses: control lenses, which were their best sphere (spherical correction - ½cylinder correction), and lenses with an addition of +3.00 D, +1.50 D, -1.50 D, -3.00 D and -5.00 D, respectively. The order in which these different powered lenses were worn was randomized. After insertion of the contact lenses, visual acuity was measured at the testing distance with a logMAR Near Card and the near point of accommodation was measured with a RAF ruler. The fit of the contact lens was acceptable for all subjects, and the necessary contact lens adaptation time was allowed before the experimental sessions began. None of the subjects reported eye discomfort during the experiment. Subjects performed two practice runs prior to the experiment. They were allowed to take breaks between the tasks, in which case calibration of the eye tracker was repeated before starting the next task. Subjects were instructed to maintain attention, and they were continuously reminded of the importance of keeping the target clear during the experiment. Depending on the need for breaks and the ease of contact lens insertion and eye movement recording, the experiment lasted between 60 and 90 minutes.

Saccade Task. Each trial started with the appearance of a fixation cross at the center of the screen, which was visible for one second. When the fixation cross was extinguished, the stimulus simultaneously appeared at one of eight possible positions, chosen at random, which was placed at the vertices of a regular octogon, 5° from the fixation cross. The stimulus was visible for one second. When the stimulus was extinguished, the fixation cross re-appeared immediately, signaling the start of a new trial. Subjects were instructed to look at the stimulus as quickly and accurately as possible. The saccade task consisted of 24 trials.

Fixation Task. The fixation task was identical to the saccade task except the stimulus was visible for three seconds. Subjects were additionally instructed to maintain fixation for as long as the stimulus was visible and to keep focus on the stimulus at all times. The fixation task consisted of 16 trials.

The number of saccade and fixation trials has been shown to be sufficient to obtain good internal consistency for healthy young adults (Vikesdal & Langaas, 2016).

Data Analysis

The first trial of each task and trials that had blinks were not included in the analysis.

Saccade latency. Saccade latency was defined as the time at which eye velocity exceeded 20°/s for more than 32 ms after stimulus appearance (i.e., 4 consecutive eye tracker sampling points). This velocity threshold has been used in previous, similar research (Biscaldi, Fischer, & Hartnegg, 2000; Klein & Fischer, 2005). Each trial elicited one saccade (the return saccade for next trial was not included in the analysis). 2448 trials were analyzed, 185 (8.2%) were excluded (due to first trials or blinks).

Fixation stability. Saccadic suppression typically persist for approximately 80 ms after the end of a saccade (Holmqvist et al., 2011). The fixation period was therefore defined to start 80 ms after saccade offset and to end 80 ms prior to saccade onset. Each trial elicited one fixation period, fixations of the cross in the center of the screen was not included in the analysis. Fixation stability at the different locations were collapsed for each participant in each condition. To obtain likeness of fixation durations across subjects and trials, fixations lasting less than 50 sampling points, or 0.4 s, were also excluded from analysis. 1632 trials were analyzed, 158 (10.7%) were excluded (due to first trials, blinks or fixations lasting less than 0.4 s).

The sampling frequency of the eye movement recorder (120 Hz) was too low to detect microsaccades. Therefore, 'fixation stability' refers to 'eye position dispersion during the fixation task'. We used the denomination bivariate contour ellipse area (BCEA) to define the stability of fixation, which refer to the area in which the eye is positioned a certain percentage of the time. This method of reporting fixation stability was first introduced by Steinman (Robert M. Steinman, 1965) and is considered more complete than the use of standard deviation, as it takes into account the correlation between x and y coordinates (Castet & Crossland, 2012). The BCEA is calculated by equation 1 (Eq. 1).

$$BCEA = k\pi\ (\sigma H \sigma V)\sqrt{1-\rho^2}$$

Eq. 1 Calculation of the bivariate Contour Ellipse Area. σH and σV are the standard deviation of eye position coordinates, and ρ is the product-moment correlation of the two position components.

In equation 1, σH and σV refer to the standard deviation of horizontal and vertical eye position coordinates, respectively, measured in degrees and ρ is the product-moment correlation of the two position components. k is a chi-square variable with two degrees of freedom, commonly set to 2.291 so that the BCEA encompasses 68.2% of the highest density points, known as a P-value of 68.2% (Castet & Crossland, 2012). The BCEA presupposes that the distribution of fixation points is Gaussian, which has been shown to be a reasonable assumption, at least for people with good visual acuity (Robert M. Steinman, 1965). For statistical analysis we used logBCEA (arcmin^2) to approximate normal distribution (Amore et al., 2013; Cesareo et al., 2014). We have previously shown that logBCEA (arcmin^2) including 68.2% of highest density points is a reliable measure of fixation stability with good internal consistency (Vikesdal & Langaas, 2016).

Statistics

Statistical analysis was performed using the IBM© SPSS Statistics version 22 (Copyright IBM Corp. and other(s), 1989, 2013). The α level was set at 0.05. To check for normality in our data, the one-sample Kolmogorov-Smirnov test was performed.

Saccade latency was normally distributed for the 'Control' condition and the 'Accommodative' condition, but not for the 'Blurred' condition (p=.200, p=.200, p=.010, respectively). The non-parametric test related-samples Wilcoxon signed rank test was used to analyze differences in saccade latency between conditions.

LogBCEA was normally distributed for all conditions (p=.200, p=.200, p=.200, respectively). Repeated measure one-way analysis of variance (ANOVA) was used to analyze differences in fixation stability between test conditions, and paired t-tests were used for pairwise comparison.

Results

All participants had visual acuity equal to or better than logMAR 0.0 at the testing distance, and near point of accommodation equal to or better than expected value according to Hofstetter's formula (Scheiman & Wick, 2002). Visual acuity were measured at the experimental testing distance (1.0 m) and near point of accommodation were measured with a RAF ruler, whilst subjects wore the different experimental lenses. Data were grouped according to the effect the lenses had on visual acuity and near point of accommodation; conditions were called 'Control', 'Blurred' and 'Accommodative'. Conditions are described in Table 1.

Table 1
Description of conditions.

	Control (n=16)	Blurred (n=16)	Accommodative (n=16)
Definition	VA≤ logMAR 0.1 NPA ≥ EV-2D*	VA> logMAR 0.1 NPA ≥ EV*	VA≤ logMAR 0.1 NPA < EV-2D*
Saccade trials (mean ± SD)	23.9 (± 5.7)	49.2 (± 16.4)	45.6 (± 17.4)
Fixation trials (mean ± SD)	15.5 (± 4.7)	30.4 (± 12.3)	30.4 (± 10.7)

*Note. VA = visual acuity, NPA = near point of accommodation. D = diopters. *EV = Expected value = 18-⅓age (Hofstetter formula). 2 D is equivalent to one standard deviation from expected value (Scheiman & Wick, 2002).*

Some of the subjects had similar visual acuity and near point of accommodation with more than one pair of contact lenses. This resulted in more trials in some of the conditions, which were averaged, so that each participant ended up with one mean saccade latency and one mean fixation stability per condition. Table 2 shows an example of how the data were grouped. This way of grouping the data ensured that all trials in the 'Blurred' condition were recorded with an actual reduction in visual acuity and minimized the risk of intermittent blur due to transient accommodation in the other conditions. Also, the number of tested participants in each condition remained sixteen.

Table 2
Saccade latency and fixation stability from wearing the different lenses were grouped as in this example for one participant.

Condition	Blurred	Control			Accommodative	
Lens Power	+3.00	+1.50	0.00	-1.50	-3.00	-5.00
VA (logMAR)	0.53	-0.10	-0.10	-0.10	-0.10	0.00
NPA (D) (expected 11.0 D)	20.0	16.0	13.0	12.0	7.5	5.5

Note. VA = visual acuity, NPA = near point of accommodation D = diopters.

Mean (± standard error) saccade latency was 207.6 (±5.0) ms in the ‘Control’ condition, 208.2 (±5.8) ms in the ‘Blurred’ condition and 207.2 (±5.9) ms in the ‘Accommodative’ condition. There were no differences in saccade latency between the groups (related-samples Wilcoxon signed rank test) (figure 1).

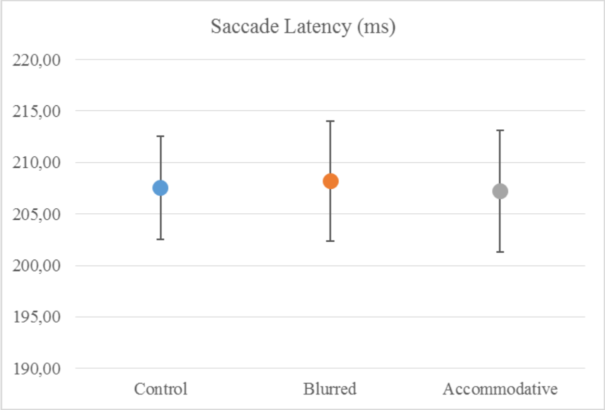

Figure 1. Saccade Latency were similar across conditions.

Mean (± standard error) logBCEA was 2.48 (± 0.03) arcmin^2 in the ‘Control’ condition, 2.57 (± 0.04) arcmin^2 in the ‘Blurred’ condition and 2.56 (± 0.03) arcmin^2 in the ‘Accommodative’ condition. The conditions were significantly different (repeated measure ANOVA, V = 0.532, $F_{2,14}$ = 7.964, p =.005), both the ‘Blurred’ condition (t = -3.963, df = 15, p = .001) and the ‘Accommodative’ condition (t = -2.194, df = 15, p = .044) were different from the ‘Control’ condition (figure 2).

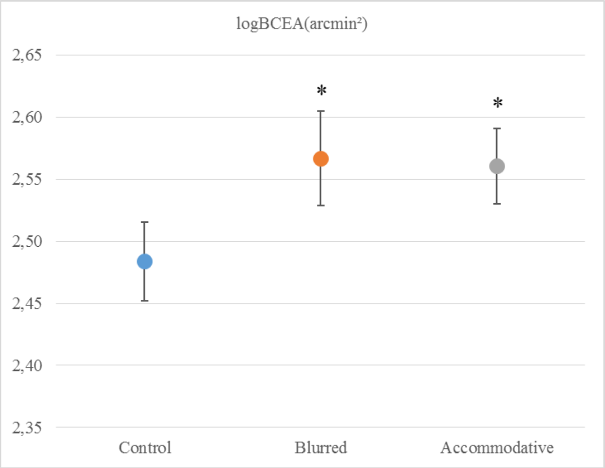

Figure 2. Fixation stability were different across conditions.

Discussion

This study did not show any effect of optically induced moderate refractive errors on saccade latency, which remained around 207 ms for all the test conditions. Saccade latency values in this study are consistent with other studies that have used comparable tasks (Bednarek et al., 2006; Klein & Fischer, 2005). The finding that saccades are not influenced by visual disturbance supports the idea that they are mainly under “open-loop” or ballistic control. On the other hand, fixation was less stable with both blur induced by plus lenses and with accommodation induced by minus lenses. Other studies that have looked at fixation stability in adults have found comparable values to our own (Crossland & Rubin, 2002). Gonzales et al used a similar setup but with a closer viewing distance of 60 cm and a 3° fixation cross, which was fixated for 15 seconds (Gonzalez et al., 2012) They found that fixation stability in healthy adults under binocular viewing conditions was logBCEA -0.88 deg^2, which translates to logBCEA 2.67 arcmin^2. In the present study, the best fixation stability (recorded in the ‘Control’ condition) was logBCEA 2.48 arcmin^2, considerably better than in the Gonzales study, presumably due to our shorter fixation period (3 seconds vs. 15 seconds). In a previous study, we found that fixation stability measured in healthy adults wearing a contact lens with correct refraction was logBCEA 2.52 arcmin², slightly degraded compared to measuring without wearing a contact lens. From this, we concluded that researchers should consider measuring participants without their contact lenses, if refractive errors are small (Vikesdal & Langaas, 2016). The present study finds that fixations stability decreases to logBCEA 2.57 arcmin² with blur induced by +1.50 or +3.00 lenses that led to a visual acuity poorer than logMAR 0.10. Our findings of poorer fixation with blurred visual input are consistent with the results of Gonzales et al, who found that degraded visual input from an amblyopic eye resulted in poor fixation stability in the unaffected eye (Gonzalez et al., 2012). In a different study, Ukwade and Bedell reported a reduction in fixation stability of 3.1 arcmin² (standard deviation of eye position) with optical blur that was introduced using trial lenses of 2-4 D (Ukwade & Bedell, 1993). Their participants maintained reasonably good fixation with all trial lenses, and the reduction in fixation stability was judged to be “of little functional importance” - and they concluded that clinical studies could disregard refractive errors up to 4.0 D (Ukwade & Bedell, 1993). Our results show that fixation stability measured by logBCEA arcmin² decline with blur by about 0.09 log units, which translates to 7.943 arcmin². The study from Ukwade and Bedell was performed at 2 m distance and a considerably longer fixation period lasting for 20 seconds. However, they had a more rigid setup with participants using a bitebar during the experiment, which can explain their findings of more stable fixations. Nevertheless, we have previously shown that fixation stability is reliably reported as logBCEA (Vikesdal & Langaas, 2016), in support by others (Castet & Crossland, 2012). Our findings of reduced fixation stability reported by logBCEA, in associated refractive errors cannot be disregarded. Contrasting our findings, Steinman et al found that with degraded visual acuity fixation was more accurate (R. M. Steinman et al., 2003). They concluded that the human visual system operates efficiently, in that one only fixates as accurate as necessary to complete the task, hence when the task is more difficult one fixates more accurately. Our findings suggests that fixation might be more vulnerable to visual disturbance than Steinman et al assumed.

Accommodative effort also degraded fixation stability by a similar amount, about 0.08 log units. This is particularly interesting given that participants had good visual acuity at the testing distance. It could imply that when subjects were accommodating by a certain amount, fixation stability was impaired even if they could see the target clearly. However, even if visual acuity was measured just before testing, it does not rule out the possibility of intermittent blur during the experiment. Our study defined accommodative effort as being more than 2 D below expected near point of accommodation for age. From clinical observations, we know that a remote near point of accommodation may lead to intermittent blur at close testing distances. However, participants were carefully instructed to keep the target clear at all times during testing, and the test distance were 1 m, not particularly close. In addition, the variability of fixation stability were similar for all conditions. Hence, the finding of a reduced fixation stability with accommodative effort seems to be a reliable finding, suggesting that poor accommodation is a contributing factor in the findings of poor fixation stability in patients groups. Future studies should target this issue further by investigating fixation stability in patient groups with and without accommodative disorders.

Our findings support the hypothesis that both decreased visual acuity and increased accommodative response leads to a more unstable fixation, but does not support the suggested connection between unstable fixation and saccadic delay.

Conclusion

In this study, induced refractive errors influenced fixation stability but saccadic latency remained relatively stable within the range of -5.0 D to +3.0 D. Since saccadic latency and fixation stability responded differently to the induced refractive errors, the results do not support the idea of a common neural control mechanism for fixation and saccades.

It has not been ruled out whether our results can be replicated in subjects with real accommodative disorders or degraded vision. Nonetheless, our results indicate that researchers should be aware that uncorrected refractive errors may potentially influence the recording of fixation stability, and for experimental studies that have a high accuracy demand, we recommend that subjects should be corrected to normal visual acuity with a minimal accommodative load. Saccade latency may be recorded without correction of moderate refractive errors.

Acknowledgements

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

Amore, F. M., Fasciani, R., Silvestri, V., Crossland, M. D., de Waure, C., Cruciani, F., et al. (2013). Relationship between fixation stability measured with MP-1 and reading performance. *Ophthalmic and Physiological Optics, 33*(5), 611-617.

Bednarek, D. B., Tarnowski, A., & Grabowska, A. (2006). Latencies of stimulus-driven eye movements are shorter in dyslexic subjects. *Brain and Cognition, 60*(1), 64-69.

Biscaldi, M., Fischer, B., & Hartnegg, K. (2000). Voluntary saccadic control in dyslexia. *Perception, 29*(5), 509-521.

Biscaldi, M., Gezeck, S., & Stuhr, V. (1998). Poor saccadic control correlates with dyslexia. *Neuropsychologia, 36*(11), 1189-1202.

Castet, E., & Crossland, M. (2012). Quantifying eye stability during a fixation task: a review of definitions and methods. *Seeing Perceiving, 25*(5), 449-469.

Cesareo, M., Manca, D., Ciuffoletti, E., De Giovanni, V., Ricci, F., Nucci, C., et al. (2014). Evaluation of fixation stability using different targets with the MP1 microperimeter. *International Ophthalmology*.

Crossland, M. D., & Rubin, G. S. (2002). The use of an infrared eyetracker to measure fixation stability. *Optometry and Vision Science, 79*(11), 735-739.

Ettinger, U., Kumari, V., Crawford, T. J., Davis, R. E., Sharma, T., & Corr, P. J. (2003). Reliability of smooth pursuit, fixation, and saccadic eye movements. *Psychophysiology., 40*(4), 620-628.

Gonzalez, E. G., Wong, A. M., Niechwiej-Szwedo, E., Tarita-Nistor, L., & Steinbach, M. J. (2012). Eye position stability in amblyopia and in normal binocular vision. *Investigative Ophthalmology & Visual Science, 53*(9), 5386-5394.

Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., & van de Weijer, J. (2011). *Eye Tracking - A Comprehensive Guide to Methods and Measures* (1 ed.). New York: Oxford University Press.

ISCAN, I. (2003). Operating Instructions Iscan ETL-300.

Klein, C., & Fischer, B. (2005). Instrumental and test-retest reliability of saccadic measures. *Biological Psychology, 68*(3), 201-213.

McKee, S. P., Levi, D. M., Schor, C. M., & Movshon, J. A. (2016). Saccadic latency in amblyopia. [Research Support, N.I.H., Extramural]. *Journal of Vision, 16*(5), 3. doi: 10.1167/1116.1165.1163.

Niechwiej-Szwedo, E., Kennedy, S. A., Colpa, L., Chandrakumar, M., Goltz, H. C., & Wong, A. M. (2012). Effects of induced monocular blur versus anisometropic amblyopia on saccades, reaching, and eye-hand coordination. *Investigative Ophthalmology & Visual Science, 53*(8), 4354-4362.

Otero-Millan, J., Macknik, S. L., & Martinez-Conde, S. (2014). Fixational eye movements and binocular vision. *Frontiers in integrative neuroscience, 8*, 52.

Rommelse, N. N., Van der Stigchel, S., & Sergeant, J. A. (2008). A review on eye movement studies in childhood and adolescent psychiatry. *Brain and Cognition, 68*(3), 391-414.

Scheiman, M., & Wick, B. (2002). *Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders* (2nd ed. Philadelphia ed.): Lippincott Williams & Wilkins.

Steinman, R. M. (1965). Effect of Target size, Luminance and Color on Monocular Fixation *Journal of the Optical Society of America, 55*(9), 1158-1165.

Steinman, R. M., Pizlo, Z., Forofonova, T. I., & Epelboim, J. (2003). One fixates accurately in order to see clearly not because one sees clearly. *Spatial vision, 16*(3-4), 225-241.

Steinman, R. M., Skavenski, A. A., & Sansbury, R. V. (1969). Effect of lens accommodation on holding the eye in place without saccades. [Letter to editor]. *Vision Research*(9), 629-631.

Ukwade, M. T., & Bedell, H. E. (1993). Stability of oculomotor fixation as a function of target contrast and blur. *Optometry and Vision Science 70*(2), 123-126.

Vikesdal, G., & Langaas, T. (2016). Saccade Latency and Fixation Stability: Repeatability and Reliability. *Journal of Eye Movement Research*, *9*(2), 1-13.

WMA. (2013). WMA Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects. http://www.wma.net/en/30publications/10policies/b3/index.html: World Medical Association.

Yang, Q., Bucci, M. P., & Kapoula, Z. (2002). The latency of saccades, vergence, and combined eye movements in children and in adults. *Investigative Ophthalmology & Visual Science, 43*(9), 2939-2949.