INDIVIDUAL DIFFERENCES IN PERFORMANCE: RANDOM DOT KINEMATOGRAMS AND AXIAL LENGTH

A thesis presented to the graduate faculty of New England College of Optometry in partial fulfillment of the requirements for the degree of Master of Science.

Christina La

May 2023

Christina La©
All rights reserved

The author hereby grants New England College of Optometry permission to reproduce and to distribute publicly paper and electronic copies of the thesis document in whole or in part.

DocuSign Envelope ID: 1FF96853-9BF5-432C-A6D7-530F0FE761DC

INDIVIDUAL DIFFERENCES IN PERFORMANCE: RANDOM DOT KINEMATOGRAMS AND AXIAL LENGTH

Christina La

This manuscript has been read and accepted by the Thesis Committee in satisfaction of the thesis requirement for the degree of Master of Science

5/10/2023
Date

DocuSigned by:
Christopher P. Taylor, Ph.D.
Graduate Faculty Advisor

5/10/2023

DocuSigned by:
Peter Bex
Peter J. Bex, Ph.D.
Thesis Committee Member

5/11/2023

DocuSigned by:
Sangeetha Metlapally
Sangeetha Metlapally, Ph.D.
Thesis Committee Member

5/11/2023

DocuSigned by:
Nicole Ross
Nicole Ross, OD, MSc
Thesis Committee Member

5/12/2023
Date

DocuSigned by:
Thanasis Pamorgias, MSc, Ph.D.
Director of Graduate Studies

New England College of Optometry

Abstract:
INDIVIDUAL DIFFERENCES IN PERFORMANCE: RANDOM DOT KINEMATOGRAMS AND AXIAL LENGTH

Christina La
New England College of Optometry, 2023

Purpose:

We aimed to explore the relationship between axial length and visual performance for a motion task that included contrast polarity, given the relationship between contrast polarity and axial length for spatial vision revealed previously. In a previous study of spatial vision in observers with a variety of axial lengths, Hogue and Taylor (2021) found detection threshold values increased with increasing axial length for both ON-contrast and OFF-contrast stimuli that were center-surround Differences of Gaussians. We designed an experiment that examined the relationship between axial length and the robustness of motion direction discrimination in the presence of noise.

Methods

The association between axial length and individual differences in psychophysical performance for positive (ON pathway stimuli) and negative (OFF pathway stimuli) contrast was studied for thirty subjects (mean age 25.37 ± 3.95 years old). The axial length of our sample ranged from 22.33 to 28.17 millimeters (Mean = 24.7 mm, Standard Deviation = 1.41 mm). A mixture of Gaussian model was applied to the A-scans obtained from the Lenstar to measure choroidal thickness.

Subjects' thresholds were measured with a four alternative forced-choice random dot kinematogram (RDK) task in which subjects were asked to identify the direction of motion

using a Nintendo-style gamepad.

Random dot kinematograms with positive and negative polarity were presented on a Vpixx 12-bit monitor. Each trial began with a fixation point of +/- 80% contrast lasting 1.2 seconds, which changed in contrast for 0.016 ms as an attention-orienting flash. After the flash, the RDK appeared on the screen for 150 ms, with each dot having a limited lifetime of 25 ms. The size of the stimulus was 3.5 degrees of visual angle. Each dot was a center-surround dot of 0.2 degrees of visual angle, 0.1 degrees of which was the diameter of the center of the dot. Each center-surround dot had a contrast of 87%. The stimulus was presented either at the center of the screen or 7 degrees above/below fixation. The stimulus moved either to the left, right, up, or down with random noise drawn from a Gaussian distribution added to each element with a variance of 5, 30, 60, or 90 degrees. Subject responses were recorded with a gamepad. Proportion correct data were collected along with response time. Subjects were provided with auditory feedback on each trial.

Three pre-planned analyses were performed. First, changes in choroid thickening and thinning were assessed using t-tests. Second, Pearson correlations were calculated to evaluate the association between visual field location and performance for both ON and OFF stimuli. Third, Pearson correlation was computed to determine if there was an association between motion direction discrimination for ON/OFF stimuli and axial length. Exploratory data analyses and results are presented in the discussion.

Results:

There was no evidence of choroid thickness changes following ON stimulation

($t = 0.30$, $df = 28$, p-value = 0.77), while there was a small choroid thickness change following OFF stimulation ($t = 0.46$, $df = 28$, p-value = 0.65). The choroid thickened following OFF stimulation instead of thinned, which was an unexpected result based on previous research. There were no significant differences in motion direction discrimination between ON and OFF stimuli in the central, upper, and lower visual fields. No significant Pearson correlations were found between the subjects' abilities to discriminate motion direction of ON and OFF stimuli across axial lengths in all visual field locations.

Our exploratory analyses showed that reverse motion illusion played a larger role than expected across all noise levels and all visual field locations for both ON and OFF contrast polarity.

Conclusion:

Unfortunately, this experiment's data did not provide evidence for our pre-planned hypotheses. In the discussion, a series of limitations are explored that may have produced our null results; specifically, the reverse motion illusion may explain our inability to detect an influence of axial length.

Acknowledgments

I would like to acknowledge and give my warmest thanks to my graduate faculty advisor, Dr. Christopher Taylor, who made this work possible. His invaluable guidance and advice carried me through all stages of this project. It was a great privilege and honor to be able to work and study beside him. I would also like to thank my thesis committee members for agreeing to be a part of my thesis committee and sharing your vast knowledge in this field of study through constructive feedback. I would like to thank the Graduate Studies professors for teaching me the skills and knowledge needed to complete this project. I would like to thank the New England College of Optometry for allowing me to conduct my research project with their facilities and funds. I would also like to thank my fellow classmates and colleagues at the New England College of Optometry who agreed to be subjects for my project.

Last but not least, I would like to give special thanks to my fiancé, parents, and sister for their endless support on my journey in the completion of this project and the OD/MS dual degree program.

1. General Introduction **1**
1.1. Myopia 1
1.1.1. Myopia Epidemic 1
1.1.2. Anatomical Differences that Indicate Myopia 2
1.1.3. Decreased Visual Performance in Myopes 4
1.1.4. Myopia Risk Factors 7
1.1.5. Classification and Quantification of Myopia 9
1.2. Motion Perception 11
1.3. Contrast Polarity 15
1.4. Choroidal Changes 18
1.5. Motivation and Aims 21
2. Methods **23**
2.1. Participants 23
2.2. Study Design 24
2.3. Ocular Biometry 25
2.4. Psychophysics 27
2.5. Data Analysis 31
3. Results **35**
3.1. Choroid Changes Following ON/OFF Stimulation 35
3.2. Performance Exclusion and Psychometric Fits 36
3.3. Equivalent Noise As a Function of Contrast Polarity 37
3.4. Equivalent Noise As a Function of Axial Length 38
4. Discussion and Conclusions **40**
4.1. Reverse Motion Illusion 40
4.2. Role of Attention 49
4.3. Differences in Upper versus Lower Visual Field
53
4.4. Limitations 56
4.5 Conclusion and Future Directions 58

Bibliography **59**

Supplemental Material **66**

List Of Tables

1. Table 1: Number of subjects excluded in each test condition and location based on psychometric performance / goodness-of-fit criteria…..……..….[PAGE 37]
2. Table 2: Demographics…….……..……..…..[PAGE 67]

List Of Figures

1. Figure 1: Topcon KR-1W wavefront analyzer and Haag-Streit Lenstar 900[PAGE 26]
2. Figure 2: A-scan from the Haag-Streit Lenstar 900…….……..…...[PAGE 27]
3. Figure 3: Vpixx 12-bit monitor……...……...…....[PAGE 28]
4. Figure 4: Still frame example of stimuli……..…….…….[PAGE 30]
5. Figure 5: Example of low and high sampling efficiency in still frame example of stimuli……....[PAGE 32]
6. Figure 6: Choroid thickness changes as a function of contrast polarity…....[PAGE 36]
7. Figure 7: Equivalent motion noise as a function of contrast polarity…….....[PAGE 38]
8. Figure 8: Equivalent motion noise as a function of axial length……..…[PAGE 39]
9. Figure 9: Probability of reverse motion illusion given incorrect responses across all noise levels for upper, center, and lower visual field for OFF and ON contrast polarity……...……[PAGE 47]
10. Figure 10: Probability of reverse motion illusion given incorrect responses across contrast polarity……..…...…...[PAGE 48]

1. General Introduction

1.1. Myopia

1.1.1. Myopia Epidemic

The prevalence of myopia is high and is continuously increasing. In China, up to 90% of teenagers and young adults are myopic today compared to sixty years ago when only 10-20% of the population was myopic (Dolgin, 2015). The United States and Europe are also affected by this myopia epidemic, with double the prevalence of myopia today compared to fifty years ago (Dolgin, 2015). By 2050, the World Health Organization estimates that half of the world's population may be myopic (Wang et al., 2021).

Although myopia may be corrected with glasses, contact lenses, or refractive surgery, the growing prevalence of myopia is a concern because elongated eyes are associated with an increased risk of developing vision-threatening conditions, such as retinal detachment, retinoschisis, retino-choroidal degeneration, glaucoma, and cataracts (Dolgin, 2015; Haarman et al., 2020). Even low levels of myopia are associated with this increased risk of ocular complications, and higher levels of myopia further increase these risks (Haarman et al., 2020; Hyman et al., 2005). In a meta-analysis by Haarman et al. (2020), patients with myopia have a 100-fold higher risk of myopic macular degeneration, a three-fold higher risk of retinal detachments, a three-fold higher risk of posterior subcapsular cataracts, and an almost doubled risk of open-angle glaucoma.

Given the increasing prevalence of myopia and the increased risk of sight-threatening complications, interest in myopia prevention and control has increased. Methods of myopia prevention target modifiable risk factors for myopia, such as spending more time outdoors

(Lanca et al., 2022). Current forms of myopia control include orthokeratology, bifocal and multifocal spectacles, contact lenses, and antimuscarinic agents (Walline, 2016). Confronting the myopia epidemic will take a two-pronged approach relying on broad population-based initiatives for myopia prevention and individualized patient care (Modjtahedl et al., 2018).

1.1.2. Anatomical Differences that Indicate Myopia

Infants are typically hyperopic and gradually develop toward emmetropia during the first years of life (Atkinson et al., 2000). Axial elongation, in the process of emmetropization, is associated with thinning of the retina, a reduced density of retinal pigment epithelium cells in the equatorial and retroequatorial region, and thinning of choroid and sclera starting at the equator and being most marked at the posterior pole (Jonas, Ohno-Matsui, Panda-Jonas, 2019). Myopia is considered a failure of emmetropization and results in different anatomical features compared to emmetropia. Early myopia studies concluded that axial length is the most important factor in determining refractive error and that most myopia is axial in nature (Grosvenor, Goss, 1998).

A steep cornea may play a role in myopia development aside from axial elongation (Grosvenor, Goss, 1998). A structural model developed by Scott and Grosvenor in 1993 showed that corneal radius and vitreous chamber depth were equally predictive of myopia. Looking at the axial length/corneal radius ratio, Grosvenor and Goss (1998) ruled out the crystalline lens power as a significant cause of myopia. During emmetropization, vitreous chamber depth increases, and crystalline power decreases (Grosvenor, Goss, 1998). By ruling out crystalline lens power as a cause of myopia, Grosvenor and Goss isolated the cornea's

role in myopia as axial length elongation. Overall, myopes tend to have steeper corneas than emmetropes (Grosvenor, Goss, 1998; Carney, Mainstone, Henderson, 1997), and it has been found that decreased peripheral corneal flattening has been associated with increasing vitreous chamber depth and increasing axial length.

One line of evidence for visual regulation of eye growth comes from animal studies that used spectacle lenses to impose defocus on the retina (Schaeffel, Feldkaemper, 2015; Wallman et al., 1995). The choroid is primarily a vascular structure supplying the outer retina. One of its functions, aside from providing vascular supply to the outer retina, is modulation of vascularization, which allows the choroid to compensate for defocus (Nickla, Wallman, 2010; Wallman et al., 1995). In chick eyes, the compensatory response consists of changes in the thickness of the choroid, moving the retina forward in myopic defocus and backward in hyperopic defocus (Nickla, Wallman, 2010). Clinical and histological studies have shown that subfoveal choroidal thickness decreases with longer axial length (Jonas, Ohno-Matsui, Panda-Jonas, 2019), which correlates with the compensatory response the choroid has with defocus.

The choroid and sclera are intimately related. One reason is that the choroid is a source of growth factors that act on neighboring tissues, which includes scleral growth regulators that control scleral remodeling (Summers, 2013; Nickla, Wallman, 2010). In addition, the choroid's synthetic activities are related to its thickness. A thicker choroid may act as a barrier to signals for elongation from the RPE or retina or facilitate access to the sclera (Nickla, Wallman, 2010). Lastly, since the choroid and sclera are neighboring tissues, the choroid area may influence the area of the sclera and hence the size of the globe. As part

of the compensatory response to defocus shown in chick studies, it has been shown that the compensatory response also consists of changes in the size of the globe, which are accompanied by changes in the synthesis of extracellular matrix macromolecules in the sclera (Nickla, Wallman, 2010). In primary axial myopia, the thickness of the sclera is decreased in the posterior half of the globe, with thinning most marked at the posterior pole and least marked at the ora serrata.

As expected, the difference in axial length between an emmetrope and a myope may lead to differences in RPE cell density and retinal thickness. RPE cell density and retinal thickness are associated with axial length in the macular region. There is a decreased density of RPE cells and a thinning of retinal layers accompanied by a longer axial length (Jonas, Ohno-Matsui, Panda-Jonas, 2019).

1.1.3. Decreased Visual Performance in Myopes

Anatomical differences between emmetropia and myopia may lead to differences in visual performance. Atchison et al. (2006) investigated the neural and optical limits to visual performance in myopia. They found that myopia influenced spatial summation by increasing the size of the critical area for detection in myopes. (Atchison et al., 2006). A difference in myope's spatial summation was observed in the temporal visual field and at fixation but not in the nasal visual field (Atchison et al., 2006).

However, in a study by Jaworski et al. (2006), which evaluated spatial summation in fixation, critical areas on the retina and contrast sensitivity changed with myopia. Specifically, the contrast sensitivity of myopes decreased at high spatial frequencies but not

low spatial frequencies, consistent with impaired spatial summation (Jaworski et al., 2006). As a result, Jaworski et al. (2006) concluded that reduced spatial summation arises from postreceptoral elements with reduced sensitivity (e.g., retinal ganglion cells with a center-surround organization).

Stoimenova (2007) investigated the correlation between the degree of myopia (defined by spherical equivalent refractive error) and contrast thresholds for Cyrillic letters presented to the fovea. The results showed that myopes have reduced contrast sensitivity despite being corrected to normal acuity, and that this is possibly due to molecular and cellular adaptations of the retina (Stoimenova, 2007). Contrast sensitivity was negatively related to the degree of myopia, which is believed to be because myopia reduces the optical quality of the retinal image with optical defocus and astigmatism (Stoimenova, 2007). However, previous studies in our lab using Sloan letters found that this result could not be replicated.

Kerber et al. (2016) examined the relationship between peripheral contrast sensitivity and attention in myopes. Kerber et al. (2016) concluded that the magnitude of the effect of central attention at more peripheral eccentricities (30° eccentricity) was greater in myopes than emmetropes. Decreased contrast sensitivity in the periphery may be caused by limits on central attentional capacity and reduced retinal blur sensitivity, which leads to differences between central and peripheral visual information processing (Kerber et al., 2016).

A study by Wei et al. in 2021 evaluated whether myopia affected peripheral motion detection at a range of spatial frequencies, speeds, and eccentricities; no reliable difference in peripheral motion sensitivity was found among emmetropes and low, medium, and high

myopes. Post-hoc analyses showed that motion detection thresholds in the lower visual field were associated with higher myopia for low spatial frequency targets at 20° eccentricity (Wei et al., 2021). Also, the results showed correlations between the degree of myopia and peripheral motion detection threshold for the nasal and superior visual field at low spatial frequency. Thus, an association between myopia on peripheral motion discrimination performance, especially at low spatial frequencies, can not be ruled out based on the data Wei et al. (2021) presented.

One suggestion is that, unlike emmetropes, myopes adopt a local processing strategy in visual tasks over a global strategy. Myopes may compensate for the loss in central vision at high spatial frequencies by improving peripheral vision at low spatial frequencies (Wei et al., 2021). Local processing refers to attention to specific details of a stimulus or information processing in a narrower, more detail-oriented way (Li et al., 2019). On the other hand, global processing refers to the processing of information in a general, more big-picture way by establishing spatial relationships among discrete local elements (Li et al., 2019; Nayar et al., 2014). The peripheral motion detection task in the experiment by Wei et al., required more local processing (Wei et al., 2021).

In a study by Kuo et al. (2018), random dot patterns were used to measure motion perception thresholds for minimum displacement (Dmn), maximum displacement (Dmax), and motion coherence. They found decreased performance on the Dmin task with more severe myopia near the periphery since the minimum displacement threshold in the superior temporal visual field correlated positively with axial length and negatively with macular thickness (Kuo et al., 2018).

In a study by Ehsaei et al. (2013), the authors compared central and peripheral visual performance between myopes and emmetropes with contrast acuity assessment. As expected, visual performance declined with increasing eccentricity for both emmetropes and myopes due to decreased density of retinal cells and greater neural pooling in the periphery (Ehsaei et al., 2013). However, myopes showed a more rapid fall-off in visual performance with eccentricity than emmetropes, which correlates to previous studies that showed peripheral retinal function is vulnerable and central visual function is preserved in myopes (Ehsaei et al., 2013). Another interesting result from the study by Ehsaei et al. (2013) was the asymmetry in the fall-off of visual performance, where the fall-off was steeper for the temporal than the nasal periphery and steeper for the inferior than the superior periphery. This finding does correlate with anatomical asymmetry in which photoreceptors and ganglion cells are denser in the nasal and superior retina than the temporal and inferior retina (Ehsaei et al., 2013). A study by Ang et al. (2020) found that the severity of myopia was associated with reduced visual acuity and contrast sensitivity, such that higher degrees of myopia and longer axial lengths are associated with decreased visual acuity and contrast sensitivity.

1.1.4. Myopia Risk Factors

The multifactorial nature of myopia and its variable definitions make myopia and dysregulated emmetropization a complex research topic. Results from research investigating myopia and myopia progression are variable due to differences in the definition of myopia, age range, duration of follow-up, and data analysis. However, there are some consistent trends in the results. Younger age, initial myopia, female sex, and family history of myopia

are associated with myopia and myopia progression (Hyman et al., 2005). In a study by Hyman et al. (2005), myopia age was the strongest predictor of myopia progression. In general, the younger the age myopia is detected, the more rapidly myopia progresses despite similarities in other baseline characteristics in older children. One hypothesis Hyman et al. had regarding this difference was that myopia in children by 6 or 7 years of age might be a different type of myopia than that which occurs at 8 years of age and older (i.e., more likely to have a genetic basis, more rapidly progressing, more likely to be at increased risk of myopia). Aside from myopia that develops at a younger age being a different type of myopia, earlier onset of myopia also leads to a longer window of myopia progression and increases the eventual amount of myopia (Jones-Jordan et al., 2021).

Hyman et al. (2005) found that males progressed by 0.16 D less than females over 3 years, with less progression observed at each follow-up visit. Several previous studies have found similar results in India, Poland, Armenia, Malaysia, Taiwan, Australia, Finland, Nepal, Singapore, and China, but opposite results were found in studies conducted in Hong Kong and Chile (Czepita, Czepita, Safranow, 2019). In a study by Xu et al. (2022), the prevalence of myopia was higher in girls than boys regardless of age and survey year between 1995 and 2014. Xu et al. (2022) attribute this gender disparity to puberty and the differences in physiological and behavioral changes during puberty between girls and boys.

Family history of myopia and genetics also play a large role in myopia development. In a study by Liang et al. (2004), the authors found that parental and sibling myopic states were associated with the risk of having myopia, highly myopic parents could accelerate the onset of myopia in their children, and axial length was associated with the parental myopic

state. Jiang et al. (2020) investigated the association of parental myopia with a higher risk of myopia among multiethnic children before school age. In their study, Jiang et al. (2020) found parental myopia was strongly associated with a higher risk of early-onset myopia before school age, especially when parental myopia was early-onset or when both parents had myopia; these results were true across Asians, Hispanic whites, non-Hispanic whites, and African Americans.

1.1.5. Classification and Quantification of Myopia

Myopia is a refractive disorder in which rays of light entering the eye parallel to the optic axis are brought into focus in front of the retina when accommodation is relaxed (Filcroft et al., 2019). Axial myopia is a myopic refractive state attributed to excessive axial elongation (Filcroft et al., 2019). In contrast, refractive myopia is a myopic refractive state attributed to an overly curved cornea or lens with increased optical power (Filcroft et al., 2019). Secondary myopia is a myopic refractive state for which a single, specific cause can be identified that is not a recognized population risk factor for myopia development (Filcroft et al., 2019).

Although there is no internationally agreed threshold for quantifying myopia severity, Filcroft et al. (2019) proposed a minimum of three quantitative categories for myopia. Myopia would be considered a condition in which the spherical equivalent refractive error of an eye is ≥ -0.50 D when ocular accommodation is relaxed (Filcroft et al., 2019). Low myopia would be a condition in which the spherical equivalent refractive error is ≥ -0.50 D and < -6.00 D, while high myopia would be a condition in which the spherical equivalent

refractive error is > -6.00 D (Filcroft et al., 2019). Filcroft et al. (2019) note that further subdivisions, such as intermediate or moderate myopia, are often used but with little consistency, so results should be reported at the standard thresholds proposed to facilitate comparison between studies. One final definition Filcroft et al. (2019) proposed was pre-myopia, which is a refractive state of an eye between +0.75 D and -0.50 D in children, where a combination of baseline refraction, age, and other quantifiable risk factors provide a sufficient likelihood of the future development of myopia.

Other methods of myopia classification include the presence of degenerative changes and age of onset (Meng et al., 2011). The presence of degenerative changes and the value of refractive error in diopters can be used to differentiate between physiological myopia and pathological myopia (Meng et al., 2011). Based on the age of onset, myopia can be divided into youth-onset (less than 20 years old), early adult-onset (between 20 and 40 years old), and late adult-onset (over 40 years old) (Meng et al., 2011).

Although axial length is the largest contributor to the determination of refractive error, it is not commonly used to classify myopia severity. Historically, researchers found axial length in myopia to have a bimodal distribution with axial length of 24 mm for low myopia (refractive error between 0.00 D and -6.00 D) and axial length of 30 mm for high myopia (refractive error > -6.00 D) (Meng et al., 2011). Meng et al. (2011) note that the bimodal distribution of axial length indicates different physiopathological mechanisms of myopia and why it is necessary to differentiate myopia severity in data analysis in research.

1.2. Motion Perception

Motion is one of the major attributes of visual processing, especially since we live in a dynamic world where objects are constantly changing and moving. Therefore, it is important to delve into the variety of mechanisms that contribute to visual motion processing to understand how we navigate our world and how it affects our development.

Visual motion processing can be organized into lower and higher stages of processing (Nishida et al., 2018). The goal of the lower-level mechanisms is the estimation of local motion vectors from the retinal image while the goal of the higher-level mechanism is the analysis of the vector fields (Nishida et al., 2018). Motion perception is often studied with random-dot kinematograms (RDK), which consist of signal dots that move coherently in one direction independently of noise dots that move in incoherent random directions (Narasimhan and Giaschi, 2012). However, it is important to note that another type of RDK has been used extensively in the literature, RDK random element motion task, where each dot has a single base direction of motion with a random noise direction added to the individual element (e.g., Williams & Sekuler, 1984; Watamaniuk & Sekuler, 1992).

Narasimhan and Giaschi (2012) evaluated the effect of dot speed and density on the development of motion perception by comparing the performance of adults and children on a direction-discrimination task over variable speeds and densities. While the speed and densities of the dots in the RDK did not affect adult coherence thresholds, Narasimhan and Giaschi (2012) found that global motion is less mature for slower speeds than faster speeds, and for lower-density dots than higher-density dots. A study by Pilly and Seitz (2009) also found little variance in performance when the speed parameter was altered in random dot

motion algorithms. Pilly and Seitz (2009) found that parameters of contrast, spatial displacement, and temporal displacement had an important impact on performance, which highlights the importance of carefully choosing and accurately reporting the algorithmic details and parameters of the stimuli used.

Motion processing varies across the visual field. The fovea processes fine spatial information, whereas the periphery is more sensitive to temporal properties (e.g., Carrasco et al., 2003). With increasing retinal eccentricity comes an increase in receptive field size. An increase in receptive field size may lead to a decline in local motion processing due to increased internal noise from summing up information across multiple noisy peripheral inputs; this could reduce motion signals in the peripheral visual field (Bower, Bian, Andersen, 2012). Bower, Bian, and Andersen (2012) took a closer look at the relationship between retinal eccentricity and global motion processing and found that perception of coherent motion declined as a function of retinal eccentricity for stimuli presented at eccentricities greater than or equal to 22 degrees. There was no consistent effect of eccentricity on global motion discrimination for eccentricities up to 16 degrees (Bower, Bian, Andersen, 2012). This was reassuring since we decided to present our stimuli centrally as well as 7 degrees of visual angle in the upper and lower visual field in an effort to minimize any effect of eccentricity on global motion discrimination.

In addition to differences in spatial resolution of the central and peripheral field contributing to differences in motion processing, differences in the visual pathway may also play a role. The magnocellular and parvocellular pathways relay visual information from the retina to the lateral geniculate nucleus and the striate cortex (e.g., Carrasco et al., 2003). The

ratio of parvocellular to magnocellular cells decreases with eccentricity. It has been shown in macaque monkeys and cats that the speed of conduction and integration time is 20 milliseconds faster for magnocellular than parvocellular neurons (Carrasco et al., 2003). Carrasco et al. (2003) studied the relationship between visual processing speed and eccentricity with a two-alternative forced choice discrimination task. The results showed that increasing eccentricity correlated with slower processing, which is consistent with neurophysiological findings of the parvocellular to magnocellular ratio and propagation of intracortical potential (Carrasco et al., 2003).

The detection of a stimulus is affected by internal noise in the visual system and the ability to efficiently process signals (also known as sampling efficiency). Psychophysical measures of internal noise are affected by changes in optical factors such as increased light scatter, reduced retinal illumination, and optical defocus (e.g., Falkenberg, Simpson, Dutton, 2014). Sampling efficiency is an observer's ability to make use of the available stimulus information and gives a measure of how a real observer compares against an ideal observer (Pardhan et al., 1995).

Simpson, Falkenberg, and Manahilov (1995) aimed to develop and apply ideal observer models for three classical motion tasks to measure internal noise and sampling efficiency. In the first experiment, the external noise level was varied, and motion discrimination thresholds were measured for three motion tasks. These tasks were the detection of drifting gratings, direction discrimination of oppositely drifting gratings, and detection of sum of oppositely drifting gratings (Simpson, Falkenberg, and Manahilov, 1995). In the detection of drifting grafts, subjects were asked to decide whether or not the

trial contained a blank signal or a signal with an upward drifting Gabor patch (Simpson, Falkenberg, and Manahilov, 1995). In the direction discrimination task, subjects were asked to determine whether an upward drifting Gabor patch or a downward drifting Gabor patch was delivered while embedded in Gaussian white noise (Simpson, Falkenberg, and Manahilov, 1995). In the last task, the observer either received a blank signal or a simultaneous upward and downward Gabor patch embedded in noise and were asked to determine whether or not the upward and downward signal was present in the trial (Simpson, Falkenberg, and Manahilov, 1995). Sampling efficiency was about 1-2% for all observers and tasks, with the exception of the motion direction discrimination task at 6 Hz, where efficiency was lowered by a factor of 5 (Simpson, Falkenberg, and Manahilov, 1995). One hypothesis for the low efficiency in motion direction discrimination was that humans use mismatched filters and perhaps can only access filters tuned to low speeds when discriminating directions (Simpson, Falkenberg, and Manahilov, 1995). As a result, the temporal frequency was varied in the second experiment to see if the hypothesis was true (Simpson, Falkenberg, and Manahilov, 1995). Both summation and discrimination efficiency declined with temporal frequency, so Simpson, Falkenberg, and Manahilov (1995) concluded humans act as though stimuli are slower than they truly are. For all three motion tasks, the internal noise level remained constant (Simpson, Falkenberg, and Manahilov, 1995).

The development of sampling efficiency and internal noise for motion detection and discrimination in school-aged children was studied by Falkenberg, Simpson, and Dutton (2014) with three motion tasks. Similar to the study by Simpson, Falkenberg, and Manahilov in 1995, internal noise remained constant across age, task, and speed (Falkenberg, Simpson,

Dutton, 2014). In the study by Falkenberg, Simpson, Dutton (2014), the ability to discriminate the direction of moving gratings was still immature at age 14, meaning a higher signal contrast is needed for children at this age to correctly discriminate the direction of motion. Lower performance in direction discrimination could also be attributed to reduced sampling efficiency, and further development of motion discrimination is due to improved sampling efficiency (Falkenberg, Simpson, Dutton, 2014).

A study by Manning et al. (2014) suggests that averaging, but not internal noise, limits coherent motion processing. In the study by Manning et al. (2014), an equivalent noise motion integration task was presented with a traditional motion coherence task to children and adults with two-speed conditions to characterize age-related changes in internal noise and sampling, and the mechanism supporting coherent motion processing. Manning et al. (2014) found that internal noise levels decrease throughout childhood while the number of samples integrated increases, and that improvement in sampling efficiency leads to the development of motion coherence sensitivity.

1.3. Contrast Polarity

Contrast polarity and ON versus OFF pathways have been a part of vision science and our optometry practice for a long time. The concept dates back to the end of the 19th century, as seen with eye test charts developed by Dr. George Mayerle that were available in both positive and negative contrast. To date, we know the visual system is divided into ON and OFF visual pathways and include ON and OFF bipolar and ganglion cells.

The division of the ON and OFF pathways begins at the first retinal synapse between

photoreceptors and bipolar cells and continues with ganglion cells (Ravi et al., 2018). There are many retinal ganglion cell types that respond to either increments or decrements of light depending on their receptive field (Ravi et al., 2018). Retinal ganglion cells have circular receptive fields and can either be ON-center OFF-surround or OFF-center ON-surround.

Initially, the hypothesis was that ON and OFF output was equal and opposite, but evidence has begun to accumulate that the two pathways carry partially different information (Pandarinath, Victor, Nirenberg, 2010). The different ON and OFF retinal ganglion cells have similar receptive fields but with polarity reversal, so that when they are paired, they contribute to the encoding scheme for natural scenes (Ravi et al., 2018). For example, OFF-center retinal ganglion cells are twice as numerous and half the size of ON-center retinal ganglion cells. Thus, OFF-center retinal ganglion cells are better at detecting small targets. In addition, there is also a substantial difference in the temporal adaptation of ON and OFF cells to day and night, which results in a functional difference between the two (Pandarinath, Victor, Nirenberg, 2010).

In an experiment by Pandarinath, Victor, and Nirenberg (2010), temporal tuning of ON and OFF ganglion cells in the mouse retina was similar in photopic conditions but differed in scotopic conditions; during scotopic conditions, ON cells shift towards a low temporal frequency. This represents an increase in gain at low temporal frequencies and a decrease in gain at high temporal frequencies for ON cells in scotopic conditions, which corresponds to changes in signal-to-noise ratio and affects performance on temporal frequency discrimination tasks (Pandarinath, Victor, Nirenberg, 2010). In a simple discrimination task, ON cells were shown to need to observe more photons, by a factor of 3,

to match the performance of OFF cells (Pandarinath, Victor, Nirenberg, 2010).

In an experiment by van der Smagt and van de Grind in 1999, ON and OFF pathways were investigated to see if the distinction between the two pathways persisted into the integration of local motion. The ON versus OFF distinction remains partially intact with information from local motion sensors being tuned to either positive or negative contrast polarity only (van der Smagt and van de Grind, 1999). On the other hand, there are also interactions between the two systems, which is apparent when extracting global object motion, since the separate ON and OFF pathways engage in mutually inhibitory interactions (van der Smagt and van de Grind, 1999). Van der Smagt and van de Grind (1999) also found that spatial distribution of opposite contrast polarities is an important determinant in detecting an object and its motion. Small cluster-sizes resulted in equally active ON and OFF pools which equally inhibited the other's outputs (van der Smagt and van de Grind, 1999). On the other hand, increasing cluster size resulted in mutual inhibition only at the transition between clusters, which left areas where inhibition is less strong or absent (van der Smagt, van de Grind, 1999).

Mazada et al. (2019) conducted a study in which the authors examined processing different spatio-temporal properties of visual scenes in the ON and OFF cortical pathways, specifically investigating global-slow and local-fast vision. The strength of the spatiotemporal properties of the stimulus played a large role in the strength of ON and OFF cortical responses; the cortical response preference for small, fast dark stimuli and large, slow light stimuli were consistent with OFF and ON pathway specialization (Mazada et al., 2019). Mazada et al. (2019) also note that low light makes visual cortical responses weaker,

slower, noisier, and less spatiotemporally defined but preserves cortical OFF dominance and OFF spatiotemporal suppression that is needed to process local-fast vision. Overall, Mazada et al. (2019) found that OFF local-fast signals are better suited to maximize visual acuity, while ON global-slow signals were better suited for retinal image stabilization. In their discussion, Mazada et al. (2019) note that myopia has been associated with a deficit in retinal dopamine, which is released only by dopaminergic ON amacrine cells. As a result, exposure to low light can be a factor in increasing the development of myopia whereas time outdoors reduces the development of myopia. If myopia is caused by understimulation of ON visual pathways, then these results could bring about new ideas for myopia prevention (Mazada et al., 2019).

1.4. Choroid Changes

As mentioned previously, the choroid has been shown to compensate for imposed defocus (Nickla, Wallman, 2010; Wallman et al., 1995). In chick eyes, the compensatory response consists of changes in the thickness of the choroid, moving the retina forward in myopic defocus and backward in hyperopic defocus (Nickla, Wallman, 2010). In macaque monkeys, induced myopic defocus produced a rapid and dramatic increase in choroidal thickness, while induced hyperopic defocus produced decreased choroidal thickness and reduced the rate of choroidal thickening (Hung, Wallman, Smith, 2000). Similar findings of choroidal thickness modulation by visual experience have been found in tree shrews and marmosets as well (Hung, Wallman, Smith, 2000).

Such findings regarding choroidal thickness modulation have also been found in humans. Wang et al. (2016) studied the effects of optical defocus in school aged children by randomly assigning fifty-one children to a control group, a myopic defocus group, or a hyperopic defocus group. Children in the control group were fully corrected in both eyes, while children in the myopic and hyperopic defocus groups wore +3.00D and -3.00D, respectively, over full correction in the right eye while wearing full correction only in the left eye (Wang et al., 2016). Children assigned to the myopic and hyperopic defocus groups wore the defocus lenses over full correction for 2 hours, and then wore full correction only for 2 hours, while children in the control group wore full correction for 4 hours (Wang et al., 2016). During this short-term exposure to defocus, there was a small but significant change in axial length and choroidal thickness, with choroidal thickness decreasing in the hyperopic defocus group and increasing in the myopic defocus group as compared to the control group (Wang et al., 2016). In another study by Hoseini-Yazdi et al. (2019), the left eye of twenty-five healthy subjects was exposed to clear vision in the central twenty-six degrees visual field for 60 minutes as the control session, +3.00D myopic defocus full field for 60 minutes, +3.00D myopic defocus in the superior retina for 60 minutes, and +3.00D myopic defocus in the inferior retina for 60 minutes, while the right eye was occluded; these conditions occurred during four separate sessions for each subject. Choroidal thickness had decreased in the control session due to the unique stimulus conditions, and increased in the three defocus sessions (Hoseini-Yazdi et al., 2019). When the myopic defocus was limited to either the superior or inferior retina, the opposite hemifield was not affected (Hoseini-Yazdi et al., 2019). These results provide evidence supporting choroidal thickening with myopic defocus

(Wang et al., 2016; Hoseini-Yazdi et al., 2019) as well as evidence for local regional choroidal response (Hoseini-Yazdi et al., 2019).

In addition to choroidal thickness modulation in response to defocus, there has also been evidence of modulation with contrast polarity in relation to the stimulation of the ON/OFF visual pathway. Aleman, Wang, and Schaeffel (2018) investigated choroidal thickness changes by using OCT imaging before and after subjects read ON or OFF stimulating text for one hour. ON stimulating text consisted of white text on a black background while OFF stimulating text consisted of black text on a white background (Aleman, Wang, Schaeffel, 2018). Aleman, Wang, and Schaeffel (2018) found that the choroid thinned after an hour-long exposure to OFF stimulating text and the choroid thickened after an hour-long exposure to ON stimulating text. In a similar study, Hoseini-Yazdi et al. (2021) studied choroidal thickness by using OCT imaging before and after subjects read ON or OFF stimulating text for thirty minutes, as well as before and after viewing a movie with unbiased ON/OFF pathway activation. Each condition was studied at separate visits, which were conducted around the same time of day to decrease influence of diurnal variation of the choroid, and were conducted with zero diopters accommodative demand and five diopters accommodative demand (Hoseini-Yazdi et al., 2021). Overall, Hoseini-Yazdi et al. (2021) found significant choroidal thinning after stimulation of the OFF-pathway and choroidal thinning was enhanced with accommodation.

Choroidal thickness is known to have diurnal variation. Diurnal variation is an important factor to consider when studying choroidal thickness changes. In a study by Tan et al. in 2012, choroidal thickness was found to be the thickest at nine o'clock in the morning

and thinnest at five o'clock in the evening. Tan et al. (2012) also compared choroidal thickness on two different days and found a similar diurnal pattern without a significant difference between corresponding measures at the same time points. In another study by Chakraborty, Read, and Collins (2011), diurnal variations were examined for axial length, choroidal thickness, intraocular pressure and ocular biometrics. Chakraborty, Read, and Collins (2011) found a diurnal variation amongst their subjects, with the choroid being thickest at night and thinnest in the morning, which was consistent across two consecutive days of testing.

1.5. Motivation and Aims

As stated above, anatomical differences in myopes may contribute to decreased visual performance. In addition, flicker and dynamic stimuli have been proven to be effective in altering emmetropization in animal models. This is evident in a study by Lin, Taylor, and Rucker in 2020 looking at the effect of duration and temporal modulation of monochromatic light on emmetropization in chicks. This was also evident in other animal models, such as guinea pigs (Tian et al., 2019) and cats (Cremieux et al, 1989). We hope this research can contribute to the ongoing extensive research on the complex relationship between how axial length may affect visual performance and how visual performance may affect axial length.

In a previous study by Hogue and Taylor (2021), individual differences in ON/OFF pattern recognition and axial length were studied. In their study, Hogue and Taylor (2021) found that threshold values increased with increasing axial length for both the ON Difference of Gaussians and the OFF Difference of Gaussians task. Hogue and Taylor (2021) also

analyzed an OFF/ON index that was used to compare the relative sensitivity of ON versus OFF, and the result was that threshold increased more for OFF targets than ON targets.

We aim to expand on the results found by Hogue and Taylor (2021) and analyze the ON/OFF visual pathway in axial myopes with respect to temporal visual processing. We aim to evaluate this relationship by using random dot kinematograms as the stimulus. We hypothesize that threshold values will increase with increasing axial length for ON and OFF random dot kinematogram tasks, as seen in Hogue's and Taylor's spatial processing experiment. We hypothesize that the OFF/ON asymmetry, as seen in Hogue's and Taylor's spatial processing experiment, will hold for temporal processing as well.

2. Methods

2.1. Participants

Subjects were recruited from the New England College of Optometry student population. Subjects were excluded if they were younger than 18 or over 45 years of age. The experimenter obtained informed consent after explaining the study and before the subjects participated. The New England College Institutional Review Board approved the study.

A total of thirty subjects were recruited. The number of subjects was based on a related task (Hogue & Taylor, 2021) where the correlation between psychophysical performance and axial length was measured. Effect size was previously found, in that experiment, to lie between $R^2 = 0.15$ and 0.2 which gives a power with n=30 between 0.68 and 0.8.

The subjects' ages ranged from 22 to 36 years old (mean age 25.37 ± 3.95 years old). Spherical equivalent refractive error ranged from -8.69 to +0.50 D (mean -3.01 ± 2.52 D). Axial length ranged from 22.33 to 28.17 millimeters (mean 24.72 ± 1.44 millimeters). Self-identified gender makeup was 23 females and 7 males. Additional demographic information may be found in Table 2.

To ensure the distribution of this subject population was comparable to the previous study by Hogue and Taylor (2021), a Two-Sample Komolgorov-Smirnov test was used. This test revealed no evidence ($D = 0.15$, $p = 0.29$) that data from our experiment, and the Hogue and Taylor (2021) experiment were drawn from different populations.

2.2. Study Design

Each subject completed two 1.5-hour sessions conducted one or more weeks apart. Every effort was made to keep the sessions one week apart and at approximately the same time of day to account for diurnal fluctuations in choroidal thickness. However, due to scheduling conflicts with student schedules, not all subjects completed this testing exactly one week apart. During the 1.5 hour sessions, ocular biometry measurements were taken and the psychophysical task was completed.

After obtaining informed written consent, two initial assessments occurred once at the beginning of the first session. They were the completion of a questionnaire, and a measurement of refractive error with a Topcon KR-1W wavefront analyzer (Topcon, Tokyo, Japan). The questionnaire included basic demographics information, date of last eye exam, history of ocular disease, approximate age when prescribed glasses, if applicable, family history of refractive error, estimated time spent asleep/awake, the estimated amount of caffeine consumed in the past 24 hours, and estimated time spent reading and/or studying (see Supplemental Material for the specific questions).

Assessments that occurred during both sessions consisted of ocular biometry and the psychophysical task. Ocular biometry was measured before and after the completion of the psychophysical task. The psychophysical task consisted of either a stimulus that predominantly stimulated the OFF pathway or the ON pathway. The ON and OFF stimuli were never both encountered during a single session. The ON/OFF contrast polarity was counterbalanced among the subjects to minimize task order effects.

This study was pre-registered using Open Science Framework (OSF) before data collection and data analysis. Pre-registration is helpful to limit researcher degrees-of-freedom in the design and collection of data, make hypotheses explicit, and ensure the planned methodology, and analyses are adhered to; our pre-registration of this study is online https://osf.io/j92xc.

2.3. Ocular Biometry

Ocular biometry measurements consisted of refractive error, axial length, and choroidal thickness. Refractive error was measured once at the beginning of the first visit using a Topcon KR-1W wavefront analyzer (Topcon, Tokyo, Japan). A-scan measurements were captured twice during each session, once before and once after completing the psychophysical task, using a Haag-Streit Lenstar 900 (Haag-Streit, Bern, Switzerland). A total of five A-scans were captured for each eye and the five A-scans were averaged each time the A-scans were captured. Axial length is one of the parameters measured when the A-scan is captured. The axial length measurement obtained prior to completion of the psychophysical task in the first session was considered baseline and was used as the subjects' axial length in data analysis.



Figure 1*:* The left image shows the Topcon KR-1W wavefront analyzer (Topcon, Tokyo, Japan), while the right image shows the Haag-Streit Lenstar 900 (Haag-Streit, Bern, Switzerland).

Choroidal thickness measurements were extrapolated from the Lenstar A-scans obtained for each eye before and after the completion of the psychophysical task in both sessions. This process involved a mixture of Gaussian model developed in R (R Core Team 2021). First, the peaks on the A-scan representing the RPE and the choroid scleral border were isolated using Gaussian fits. The RPE produces a narrow spectral density, while the choroid scleral border produces a wider spectral density. With the mixture of Gaussian model, these peaks were repeatedly isolated. The distance between the peaks of the two Gaussian functions was selected as the biomarker of choroidal thickness. The distance was initially recorded in arbitrary units and converted to microns.

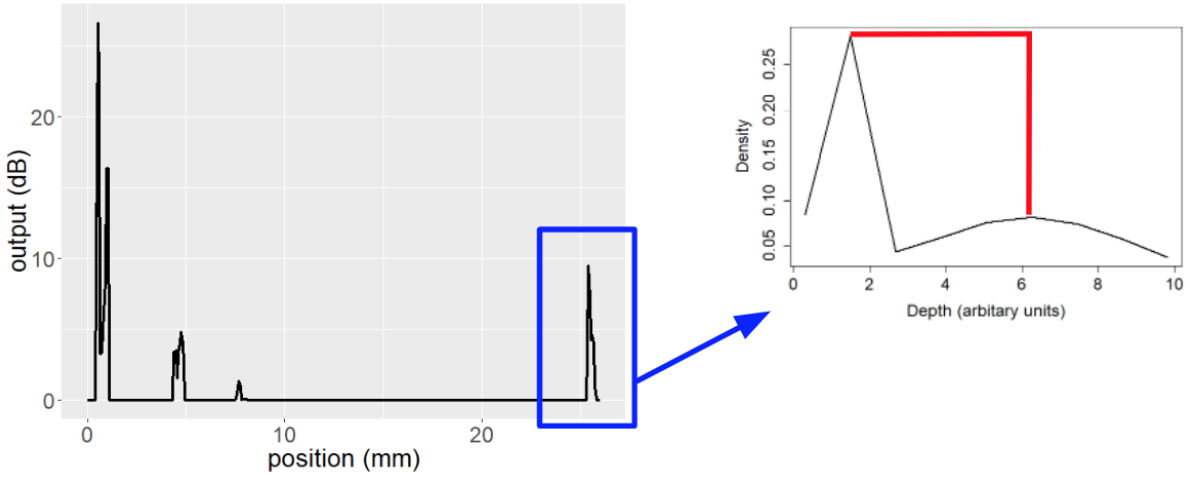


Figure 2: On the left is an example of an A-scan from the Haag-Streit Lenstar 900 (Haag-Streit, Bern, Switzerland). The first double peak represents the anterior and posterior cornea. The next peak represents the anterior lens and is followed by the peak representing the posterior lens. On a closer look, the final peak represents the retina, which has spikes representing the RPE and choroid scleral border. An example of the Gaussian fits of the RPE and choroid scleral border is on the right, with the distance between the peaks representing the chroidal thickness in arbitrary units. The final choroidal thickness measurement was calculated after converting the arbitrary units to microns.

2.4. Psychophysics

The psychophysical task was a four-alternative forced-choice random-dot kinematogram (RDK) task presented on a Vpixx 12-bit 120 Hz monitor (ViewPixx, Montreal, Canada). The average luminance of the monitor was 51.7 cd/m^2 . The stimuli in the psychophysical task were computed and displayed via MatLab as well as the video and

psychophysics toolboxes (Brainard, 1997; Kleiner 2007). Subjects were seated 57 centimeters away from the monitor with their heads stabilized in a chin-forehead rest.



Figure 3: The above image shows the Vpixx 12-bit monitor (ViewPixx, Montreal, Canada).

During the psychophysical task, participants were presented with a RDK stimulus, and their task was to determine whether the overall direction of motion was upward, downward, leftward, or rightward. This stimulus was presented either foveally or at 7 degrees in the upper or lower periphery.

The amount of external noise in the RDK stimulus was drawn from a uniform/normal distribution. Each dot within the RDK stimulus moved in the target direction, and 5, 30, 60, or 90 degrees of direction variance was applied. For example, in a RDK stimulus with an upwards target direction and 5 degrees of direction variance, each dot moved upwards and had a random number between the deviation of -5 to 5 added. Each session consisted of 1200 trials, with 100 trials occurring at one of the three locations and with one of the four

external noise levels. The location and external noise levels were randomized with each RDK presentation.

There was a fixation dot on the center of the screen. The fixation dot lasted 1.2 seconds and changed in contrast for 0.016ms as an attention-oriented flash. The fixation dot flashed black in the OFF condition and white in the ON condition with +/- 80% contrast. While this contrast is lower than what is typically used in cueing experiments, it is still quite salient and should have been effective in directing the observer's attention and helping to ensure fixation. The fixation dot was flashed 1.68 milliseconds prior to the presentation of the stimulus. The lifetime of each dot in the random dot kinematogram was 25 milliseconds, and the total stimulus duration of the random dot kinematogram was 150 milliseconds. The reason for the brief duration of the stimuli was to counter any eye-movement artifacts.

The maximum luminance of the ON and OFF dots was 95.2 cd/m^2, and the minimum luminance of the ON and OFF dots was 6.4 cd/m^2. The ON and OFF dots had a Michelson contrast of 87%. The center-surround dots were designed to preferentially activate either the ON- or OFF pathway. The diameter of the center of the dot was 0.1 degrees of visual angle, and the diameter of the surround was 0.2 degrees of visual angle. The size of the whole 100 dot field was 3.5 degrees of visual angle.

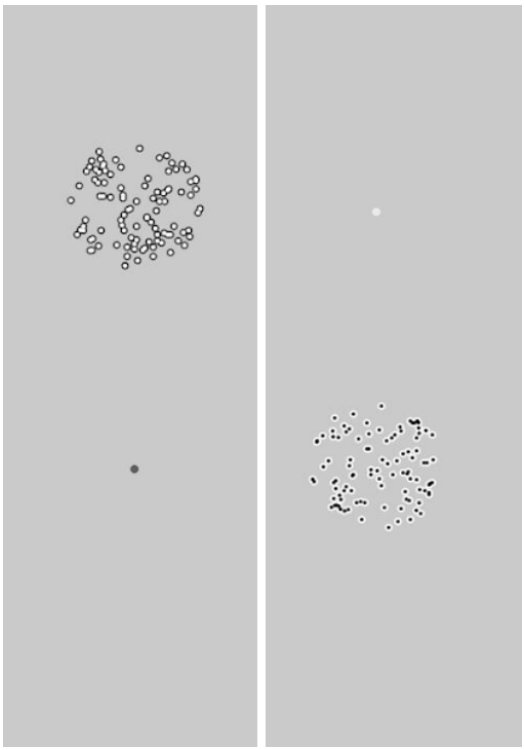


Figure 4: The image on the left is a still frame example of the ON-centered random-dot motion stimuli presented 7 degrees above fixation, while the image on the right is a still frame example of the OFF-centered random-dot stimuli presented 7 degrees below fixation. Please note the still frames have been cropped from screen captures of the entire screen to depict examples of the stimuli in adequate size, but the fixation dot is always located in the center of the screen.

Subjects used a gamepad controller to initiate each trial and to record their responses. Auditory feedback was given after each response. A high-pitched tone was played when the response was correct, while a low-pitched tone was played when the response was incorrect. Response time was recorded, but not analyzed. Subjects completed a trial run of the psychophysical task in which the overall motion was easily identified to ensure subjects

understood and could accurately perform the task. Upon completion of the practice session, subjects began the psychophysical task. The psychophysical task was self-paced, but subjects were asked to try to be as fast and as accurate as they could with their response. Subjects were allowed to take a break at any time during the session.

2.5. Data Analysis

Choroid Thickness Changes

Choroid thickness change was calculated from averaged choroidal thickness measures taken via Lenstar before and after ON and OFF stimulation in the psychophysical experiment. Because axial length was highly correlated between the eyes for each subject and our psychophysical task was performed binocularly, choroid thickness changes were averaged between eyes for each subject for data analysis purposes. Choroid thickness change was plotted in two separate box plots representing ON and OFF contrast polarity to evaluate the relationship between choroid thickness change and contrast polarity. Changes in choroid thickening and thinning were also assessed using paired t-tests.

Equivalent Noise

Equivalent noise is defined in Equation 1, which relates sensitivity in d′ to internal noise, external noise, and sampling efficiency.

$$d' = \sqrt{\frac{\sigma_i^2 + \sigma_e^2}{n}} \quad \text{(Equation 1)}$$

In Equation 1, σ_i^2 represents internal noise, σ_e^2 represents external noise, and n represents sampling efficiency.

Each observer has a constant and inherent amount of internal noise (σ_i^2) in their visual system, which can arise at any point in the visual stream from optical blur on the retina to the random firing of neurons anywhere along the pathway to encode the signal to the observer's response (Bennett, Sekuler, Ozin, 1999).

Subjects also have their own inherent sampling efficiency (*n*) over which they extract information. As seen in Figure 5 below, one way of conceptualizing sampling efficiency is that a subject could use a smaller or larger area to process information in the stimulus. In our example, more signal dots can be summed with higher sampling efficiency, which results in a lower threshold and higher sensitivity to motion direction discrimination.

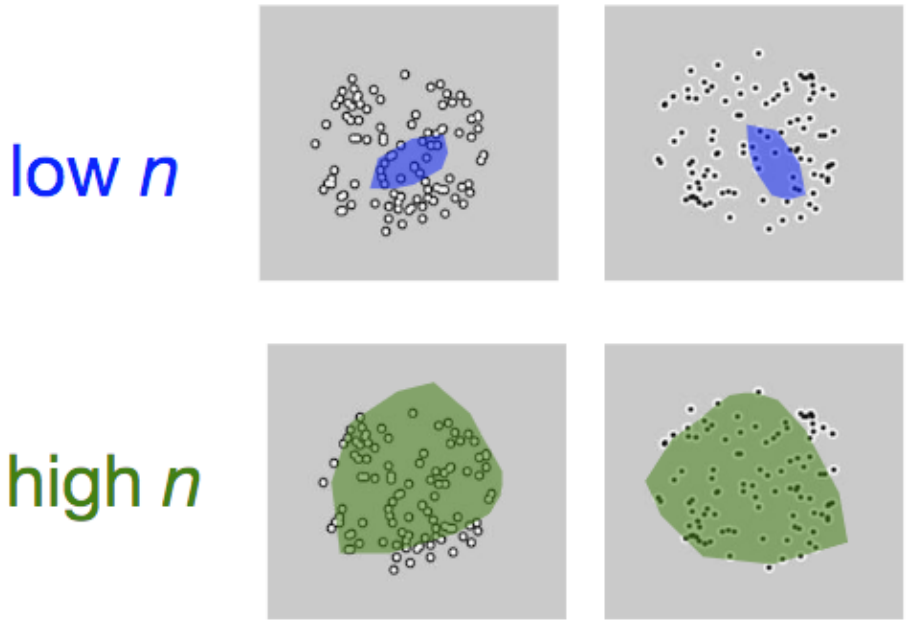


Figure 5: Examples of low and high sampling efficiency in still frame examples of the ON-centered and OFF-centered random-dot motion stimuli.

Given internal noise (σ_i^2) and sampling efficiency (n) are inherent to observers, external noise (σ_e^2) is the key variable we manipulated intending to achieve an estimate of equivalent noise in the limited time available with each subject. External noise is the direction variance we added to our RDK stimulus. Therefore, equivalent noise is the external noise (σ_e^2) experimenters need to add double an observer's threshold. Higher values of equivalent noise mean more external noise (σ_e^2) was required to double an observer's threshold or halve an observer's sensitivity (d′) to motion direction discrimination.

The d′ value was calculated for each subject at each of the three stimulus locations and each of the four levels of external noise in both the ON and OFF stimulus conditions. The d′ value is a measure of sensitivity, and in this study, it represents the subject's ability to determine the overall direction of the RDK stimulus correctly. A d′ value of 0.25, which corresponds to approximately 30% correct (Macmillan & Creelman, 2004), was used to determine whether or not subjects had succeeded or failed in terms of performance for this task. Subjects with a d′ less than 0.25 at the easiest stimulus (5 deg external noise) were excluded from data analysis for each test condition and location.

After excluding subjects who did not successfully complete the task, the results were plotted to evaluate the relationship between equivalent motion noise and contrast polarity. Equivalent motion noise was plotted against contrast polarity in three separate box plots that represented the central, upper, and lower visual fields to evaluate the relationship between equivalent motion noise and contrast polarity in each area of the visual field in which the RDK stimuli were presented. Equivalent motion noise was also plotted against axial length in three separate scatter plots that represented the central, upper, and lower visual fields to

evaluate the relationship between equivalent noise and axial length in each area of the visual field in which the RDK stimuli were presented; results from both the ON- and OFF- RDK were plotted on each scatter plot, so the effect of ON versus OFF processing could be analyzed with respect to the relationship between equivalent motion noise and axial length. Pearson correlations were calculated to help determine if there was an association between axial length and contrast polarity at each of the visual field locations.

For all analyses, the conventional alpha level of 0.05 was used.

3. Results

3.1. Choroid Changes Following ON/OFF Stimulation

Choroid thickness changes following ON and OFF stimulation were averaged between eyes for each subject. Based on previous studies, as mentioned in Section 1.4, the expected choroid thickness changes following ON stimulation is choroidal thickening. In contrast, the expected choroid thickness changes following OFF stimulation trended to choroidal thinning. Our experiment showed no significant choroid thickness change following ON stimulation ($t = 0.30$, $df = 28$, p-value = 0.77) (*Figure 6*). While there was a small choroid thickness change following OFF stimulation ($t = 0.46$, $df = 28$, $p = 0.65$) in our experiment, the thickness change was choroid thickening (*Figure 6*), which is opposite to choroid thinning that was to be expected based on previous studies.

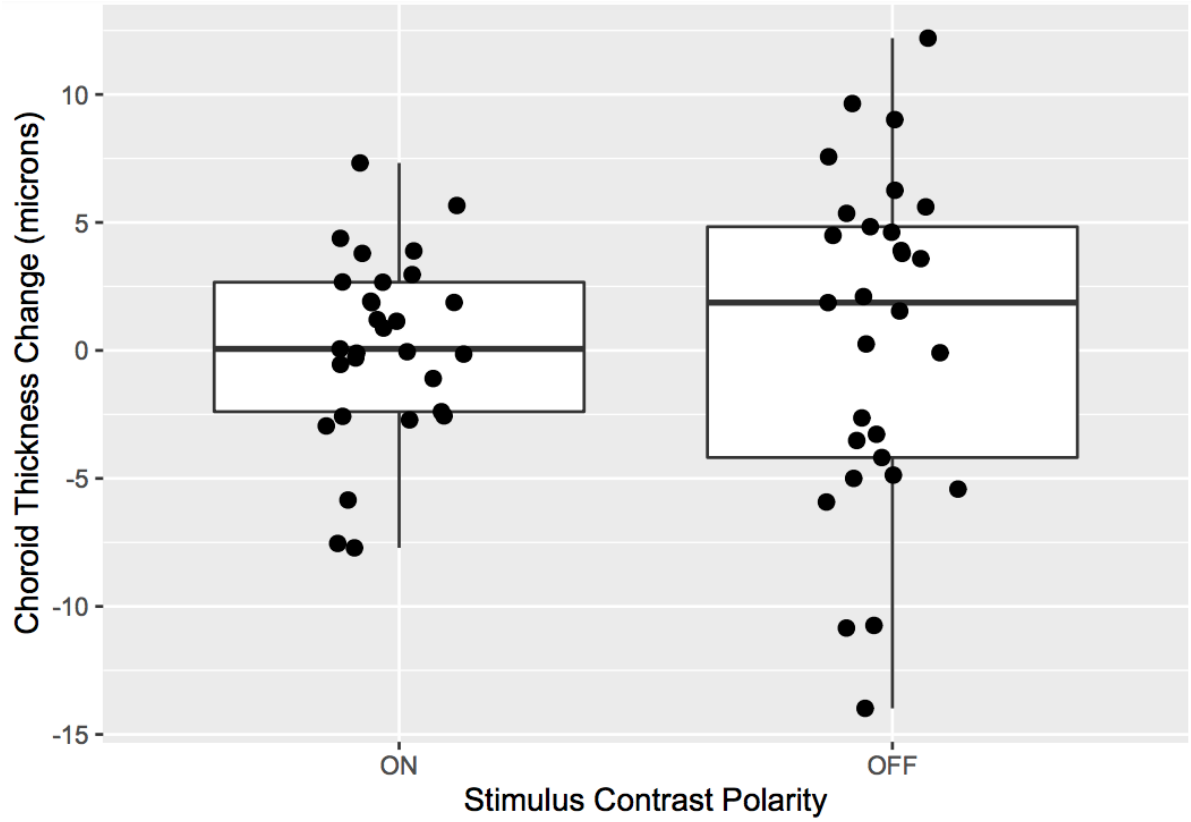


Figure 6: Choroid thickness changes following ON/OFF stimulation plotted as a function of stimulus contrast polarity.

3.2. Performance Exclusion and Psychometric Fits

As mentioned previously in section 2.1, thirty subjects participated in this research study. The Equivalent Noise Threshold was defined as a $d' = 0.25$, corresponding to approximately 30% correct (recall that this is a 4-AFC task where chance performance is 25%). However, some subjects were excluded from data analysis for each test condition and location (see section 2.5) based on goodness-of-fit criteria.

The exact number of exclusions are shown in Table 1.

	Center Visual Field	Upper Visual Field	Lower Visual Field
Number Excluded	5	8	19

Table 1: Number of subjects excluded in each test condition and location based on psychometric performance / goodness-of-fit criteria.

3.3. Equivalent Noise As A Function of Contrast Polarity

Our calculation of equivalent noise is plotted as a function of contrast polarity in three separate box plots for each visual field location in Figure 7. There was no significant difference in our subjects' abilities to extract ON versus OFF motion information in the central, upper, and lower visual fields *(Figure 7)*. This result is unsurprising based on the lack of effect of visual field location up to 16 degrees of visual angle seen in previous studies. Figure 7 also helps to highlight the stark difference in the number of exclusions made in the lower visual field compared to the central and upper visual fields.

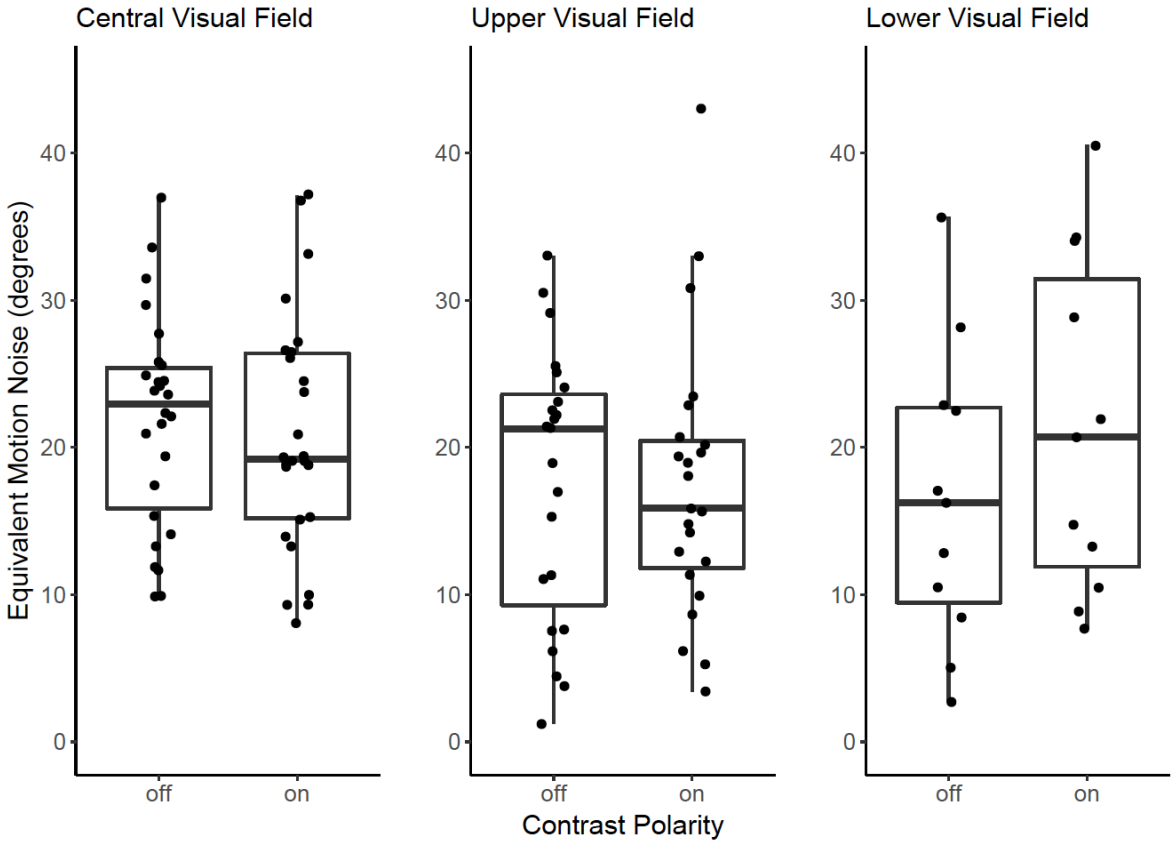


Figure 7: Equivalent motion noise for ON and OFF contrast is plotted as a function of contrast polarity for the central visual field (left), upper visual field (center), and lower visual field (right).

3.4. Equivalent Noise As A Function of Axial Length

When accounting for axial length, there was no significant difference in our subjects' ability to extract motion information with ON stimuli in the central visual field (r = -0.04, df = 24, p-value = 0.84) versus OFF stimuli in the central visual field (r = 0.18, df = 24, p-value = 0.39), ON stimuli in the upper visual field (r = 0.03, df = 21, p-value = 0.89) versus OFF stimuli in the upper visual field (r = 0.24, df = 21, p-value = 0.28), and ON stimuli in the

lower visual field (r = -0.11, df = 9, p-value = 0.75) versus OFF stimuli in the lower visual field (r = -0.39, df = 9, p-value = 0.23). Our measure of equivalent motion noise remains relatively unchanged regardless of axial length and contrast polarity *(Figure 8)*. Equivalent noise in both ON and OFF stimuli decreased slightly with increasing axial length *(Figure 8)*. Due to the large variability in performance, there are no significant correlations between axial length and performance with ON versus OFF stimuli.

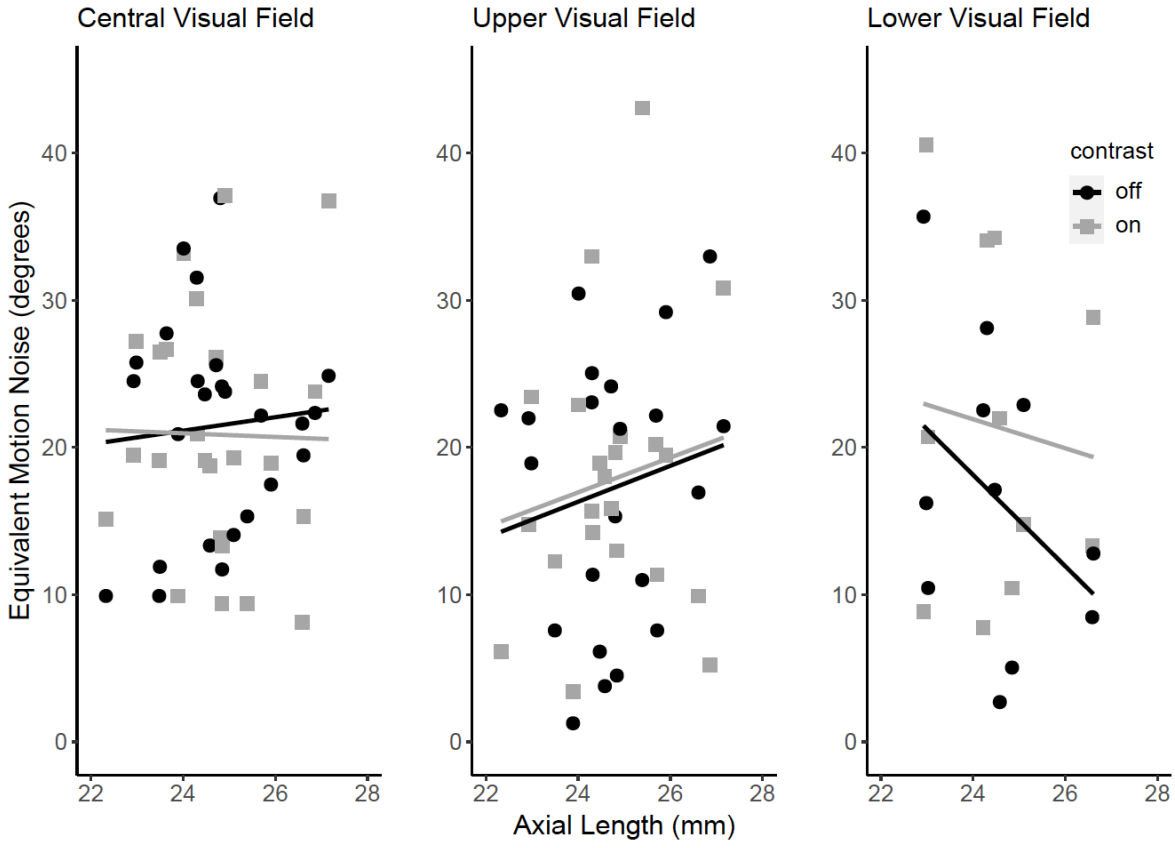


Figure 8: Equivalent motion noise for ON and OFF contrast plotted as a function of axial length for the central (left), upper (middle), and lower (right) visual fields.

4. Discussion and Conclusions

As a result of the variable performance of the subjects, there were no significant correlations between equivalent motion noise and contrast polarity or equivalent motion noise and axial length. Although there were no statistically significant results from this study related to our a priori hypotheses, could our results shed some light on aspects of visual processing and help pave the way for future research studies? Given our null results, it is important to note that our ON/OFF dot elements were of high contrast and well above threshold. Based on the prior study of spatial processing of ON/OFF stimuli by Hogue & Taylor (2021), our null results cannot be explained by reduced contrast in observers with increased axial lengths. In our discussion, we will explore possible factors and limitations in our experiment which may have contributed to our null results.

4.1. Reverse Motion Illusion

Reflecting on the results of our experiment, two features stand out. First there was a very wide distribution of individual performance in our sample, and second, most of our sample performed relatively poorly compared to a practiced psychophysical observer (Subject 30). While we did not ask our subjects for perceptual reports, one quirk of visual processing that may have played a role in our experiment is the reverse motion illusion. The reverse motion illusion refers to the situation when the observer's perceived motion direction is reversed relative to the physical stimulus motion (Manning, Meier, Giaschi, 2022).

In a recently published paper, "The reverse motion illusion in random dot motion displays and implications for understanding development," Manning, Meier, and Giaschi

(2022) explore an observation seen across their independent developmental labs, in which a small portion of their child and adult participants consistently reported perceiving motion in the direction opposite to that presented in random-dot motion displays, sometimes even when the motion is at 100% coherence. Manning, Meier, and Giaschi (2022) explore reports of reverse motion perception from studies performed in their labs as well as from other researchers. Although the proportion of children and adults found to experience the reverse motion illusion was small for Manning, Meier, and Giachi's studies, Manning, Meier, and Giaschi (2022) believe this could be an under-reported phenomenon since these participants are typically a minority of observers who are often excluded from the data set. The remainder of this section will explore the possibility that our stimulus and procedure were vulnerable to the effects thought to produce the reverse motion illusion.

Possible explanations for reverse motion illusion include motion induction, in which signal dots make noise dots appear to move in opposite directions (Manning, Meier, Giaschi, 2022). This could be the case, especially in mid-to-low levels of coherence, because the independent populations of noise and signal dots could create a percept of two surfaces sliding against each other (Manning, Meier, Giaschi, 2022). However, given that our stimulus used a RDK stimulus where each dot was both a signal and noise dot, this explanation does not apply to our stimulus.

Another possible cause of this reverse motion illusion may stem from a stimulus containing motion energy in an opposing direction, which occurs when motion in the same direction at two different spatial scales in the same stimulus cancel each other out and generate motion energy stronger in the opposing direction (Manning, Meier, Giaschi, 2022).

Unlike many studies (but for a notable exception, see Bex & Dakin, 2003) that used RDKs, our stimulus elements were not dots of a constant luminance or Gaussian blurred dots. Our stimulus dot elements had a center-surround organization (see Section 2.4), where the center of each dot had a diameter of 0.1 degrees of visual angle and the surround of each dot had a diameter of 0.2 degrees of visual angle to match stimuli presented in Hogue & Taylor (2021).

The reverse motion illusion could also be influenced by correspondence noise, which limited lifetime dots can introduce due to false correspondences between dot pairs on successive frames (Manning, Meier, Giaschi, 2022). The likelihood of false correspondences between dot pairs on successive frames increases with decreasing stimulus coherence (Manning, Meier, Giaschi, 2022). While correspondence noise may not directly lead to the reverse motion illusion, the decreased signal strength could lead to increased uncertainty and a higher probability of an incorrect response (Manning, Meier, Giaschi, 2022). To avoid the need for eye-tracking hardware and software, we used a brief RDK stimulus duration. Each dot had a limited lifetime of 25 milliseconds, and the stimulus duration was 150 milliseconds. The limited lifetime of our RDK stimulus and individual dots elements could have affected the variability of our results.

Bae and Luck (2022) also discuss the presence of reverse motion illusion in RDKs in their paper titled “Perception of opposite-direction motion in random dot kinematograms.” Bae and Luck (2022) report that opposite-direction motion was not obvious in most studies using RDKs because they usually required observers to choose between two directions. Bae and Luck (2022) performed experiments to evaluate opposite-direction motion perception across different conditions. In their first experiment, Bae and Luck (2022) examined

opposite-direction motion perception under two levels of motion coherence, 25% or 50%, and stimulus duration, 300 milliseconds or 1000 milliseconds, to evaluate if the illusion resulted from motion adaptation, such as that seen in the waterfall illusion. The waterfall illusion is based on motion aftereffect, the powerful illusion of motion in the visual image caused by prior exposure to motion in the opposite direction (Anstis, Verstraten, Mather, 1998). In the waterfall illusion, when one looks at rocks beside a waterfall, they may appear to drift upwards after one has viewed the flowing water for a short time (Anstis, Verstraten, Mather, 1998). Bae and Luck (2022) found response errors to be broader at lower coherence levels and shorter duration and attributed this to less precise perception as a result of less motion information availability. Regarding motion adaptation as seen in the waterfall illusion, Bae and Luck (2022) found that opposite-direction motion perception was just as evident at 300 milliseconds as at 1000 milliseconds, which rules out the possibility that opposite-direction motion perception is a consequence of the waterfall illusion. Our RDK stimulus had a total lifetime duration of 150 milliseconds, making it even more unlikely to be affected by the waterfall illusion given the short duration compared to the stimulus duration used by Bae and Luck (2022). It is also important to note that Bae and Luck (2022) also found a wider distribution of response error with lower coherence level and shorter duration.

In a second experiment, Bae and Luck (2022) used different monitor types and changed contrast polarity from white-on-black to black-on-white to minimize physical persistence artifacts, such as stimulus durations on the monitor being different from the signal coming from the computer's video card, and white dots on a black background potentially producing traces. To rule out these possibilities, Bae and Luck (2022) used the

same task as the first experiment but on a different computer monitor and with black dots on a white background. Since results from the second experiment were similar to the first experiment, opposite direction reports as a consequence of artifacts in stimulus presentation were ruled out (Bae and Luck, 2022). While our ON/OFF RDK stimuli were presented on a gray background, the results from this Bae and Luck (2022) experiment help to rule out physical artifacts as a factor in opposite-direction motion.

In their third experiment, Bae and Luck (2022) provided feedback about the true direction of motion after each report to ensure participants were clear about the task. Bae and Luck (2022) found that the opposite-direction reports persisted despite the addition of feedback following each trial. Similar to Bae and Luck (2022), we also provided feedback to our subjects to let them know if their response was correct or incorrect. As shown in this third experiment by Bae and Luck (2022), this feedback did not have an effect on the opposite-direction reports.

Finally, in their last experiment, Bae and Luck (2022) had observers indicate the confidence of each report, so it could be determined whether opposite-direction reports were made with high confidence. This would help determine if there was a conscious perception of opposite-direction motion rather than an unconscious bias in guessing since the opposite direction of motion was reported more than expected by chance and was not the result of stimulation artifacts or task confusion. Interestingly, the results from this last experiment by Bae and Luck (2022) showed that participants were more confident in their opposite-direction motion reports than reports that were presumably guesses (Bae, Luck, 2022). Results from the Bae and Luck (2022) experiments were consistent with the proposal that

opposite-direction reports reflect a conscious perception of the opposite direction of motion and is not entirely an unconscious response bias when participants are unsure about the direction.

Wu and Spering (2022) studied directional biases in an experiment that asked subjects to track moving RDKs with their eyes and report the object's perceived direction. The objects moved horizontally with vertical shifts of 0, ±3, ±6, or ±9 degrees and contained internal dots that were static or moved ±90 degrees up/down (Wu and Spering, 2022). Results from this experiment showed that pursuit direction was consistently biased in the direction of internal dot motion, but perceptual biases differed between observers and were related to the magnitude of pursuit bias (Wu and Spering, 2022). When there was a large pursuit bias, the perceptual and pursuit biases were aligned, but when there was a smaller pursuit bias, the perceptual and pursuit biases were in opposite directions (Wu and Spering, 2022). It is possible that smooth pursuits could have played a role in reverse motion illusion secondary to inducing motion perception from optic flow (Bex, 2023); unfortunately without eye tracking software we are unable to analyze if this could have played a role in our experiment. Although this study evaluated human smooth pursuit eye movements, which was not directly evaluated in our experiment, it reveals a dissociation between the pursuit and perception systems, which may be applicable to other visual processing systems and perception.

Exploratory Data Analysis: The Reverse Motion Illusion

So, did the reverse motion illusion play a role in our stimuli? Our exploratory data analysis described below (results shown in Figures 9 and 10) seem consistent with a claim made by (Manning et al., 2022) that RDK with independent signal and noise elements (e.g., Bae & Luck 2019 and Barbieri et al. 2018) are influenced by perceptual factors that drive the reverse motion illusion whereas RDK random element motion tasks (e.g., Williams & Sekuler, 1984; Watamaniuk & Sekuler, 1992) are not. Manning et al. (2022) base their claim on unpublished data from a conference abstract on the reverse motion illusion (Green & Pratte, 2020).

Recall from the methods that we used an RDK Gaussian motion task, where each dot element contains both motion signal and noise, whereas in RDK independent signal and noise element task dots, an individual dot is either a signal or a noise dot. Given our experiment was not designed to investigate the reverse motion illusion specifically and our analysis below is preliminary, the claim that RDK Gaussian motion tasks are less capable of inducing the reverse motion illusion merits further investigation.

In post-hoc exploratory analysis, we delved deeper into our data to look at the number of trials in which our subjects experienced the reverse motion illusion; that is, the subject reported the overall direction of motion to be exactly opposite of the actual stimulus direction (subject reported up when stimulus dots moved down, etc.). We condensed this data across all noise levels and tallied the number of trials in which reverse motion illusion occurred in the central, upper and lower visual field for ON and OFF contrast polarity for each subject (*Figure 9*). We also condensed this data across all noise levels as well as visual field

locations for ON and OFF contrast polarity for each subject (*Figure 10*). We did not condense the data across the ON and OFF contrast polarity since these were always measured during separate sessions for each subject. The dashed line represents the expected probability of the subject selecting the direction reverse from the intended stimulus direction by chance, which is 33% given the subject had selected an incorrect response and this is a 4-AFC task. We can see in both Figures 9 and 10 that the median probability that subjects selected the reverse direction of motion given an incorrect response is less than that of chance, or 33%, across noise levels and visual field location.

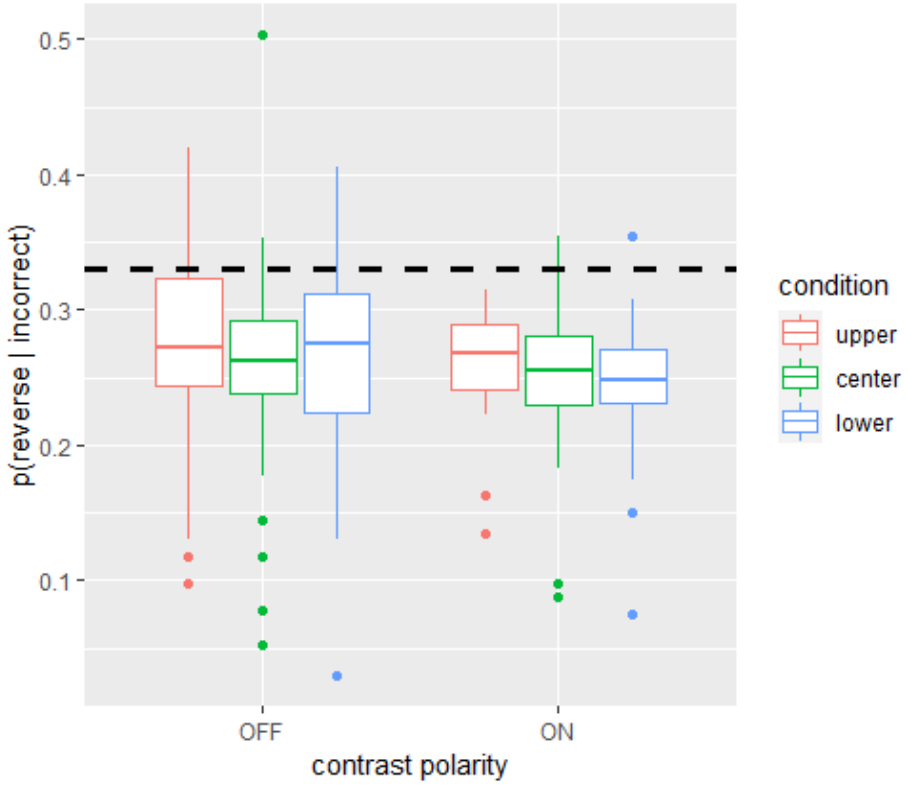


Figure 9: Probability of reverse motion illusion given incorrect responses across all noise levels for upper (red), center (green), and lower (blue) visual fields for OFF (left) and ON (right) contrast polarity.

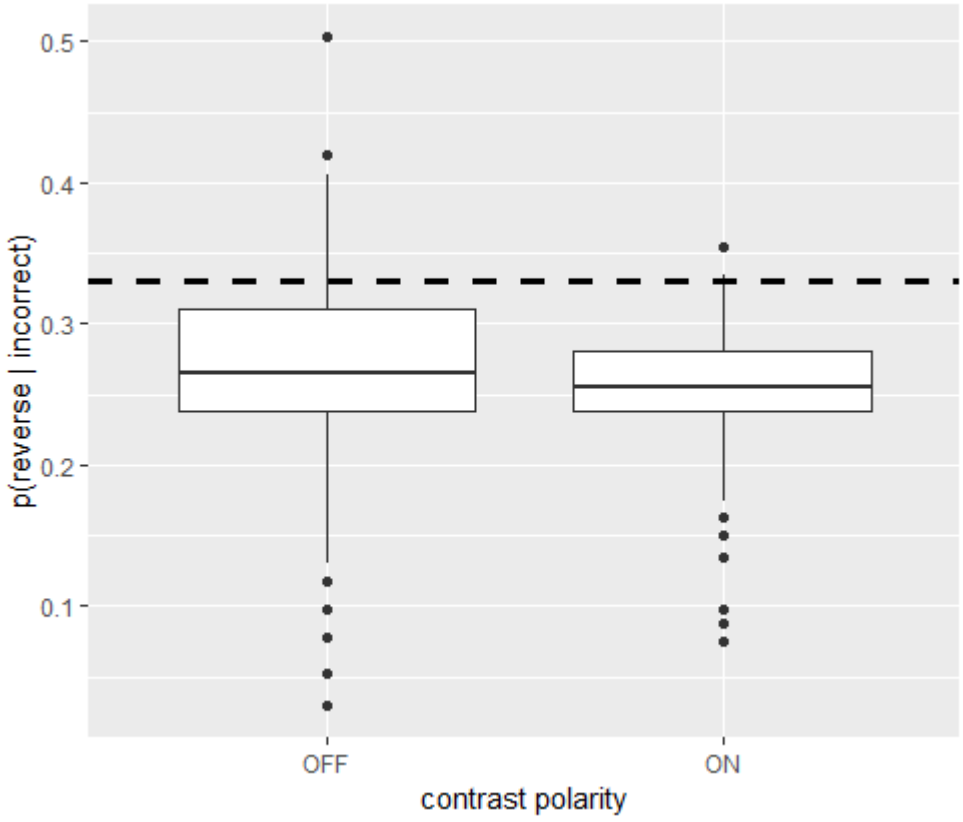


Figure 10: Probability of reverse motion illusion given incorrect responses across OFF (left) and ON (right) contrast polarity.

Although our experiment was not designed to investigate reverse motion illusion, it appears to have played a role in our results. Since our goal was not to evaluate reverse motion illusion, it is hard to discern whether this is due to our subject population being more susceptible to this illusion, or if it was the choices we made in the design of our stimulus, such as short life span and spatial uncertainty, that inadvertently evoked this illusion. One potential analysis we could complete in the future is to conditionalize our analyses based on external noise levels. As mentioned earlier, Manning, Meier, and Giaschi (2022) mentioned

decreased signal strength could lead to increased uncertainty and a higher probability of an incorrect response. By conditionalizing our analyses by external noise level, it would be interesting to see if there is a difference in reverse motion illusion between the different levels of external noise.

4.2. Role of Attention

The reverse motion illusion may have played a role in our experiment, but it is worthwhile to explore other literature related to our results. One that comes to mind is the role of attention in RDK stimuli.

Selective visual attention is the ability to base our judgment on specific parts of a scene while ignoring other parts (Murray, Sekuler, and Bennett, 2003). Selective attention can be directed to different stimuli properties, such as spatial location, color, direction of motion, spatial frequency, etc, but can be flawed at times and may be influenced by distractors (Murray, Sekuler, and Bennett, 2003). In an experiment by Murray, Sekuler, Bennett in 2003, a linear cue combination framework was used to measure selective attention as subjects made perceptual judgments. To illustrate their framework, Murray, Sekuler, and Bennett (2003) applied the framework to the question of whether observers could direct their attention according to contrast polarity when judging global direction of motion. Observers were first asked to judge the global direction of black or white RDKs, so it could be determined if the observers met the linearity assumption of the model (Murray, Sekuler, and Bennett, 2003). Then, observers were asked to judge the global direction of motion of white target dots in a RDK with either black or white distractor dots, so the method of measuring

attentional weight could be validated (Murray, Sekuler, and Bennett, 2003). Lastly, the directional selectivity for target and distractor dots could be measured to see whether selective attention led to qualitative differences in processing or if it reduced the influence of distractors on observers' responses (Murray, Sekuler, and Bennett, 2003). Overall, in the experiment, Murray, Sekuler, and Bennett (2003) showed that observers have the same selectivity for attended and unattended stimulus elements and that selective attention operates to uniformly reduce the influence of distractor elements on observers' responses. Similar to our experiment, Murray, Sekuler, and Bennett (2003) evaluated contrast polarity and judgment of the global direction of motion. Although each of our stimulus dots contained both ON and OFF characteristics as ON-center OFF-surround and OFF-center ON-surround dots versus the uniform black and white dots in Murray, Sekuler, and Bennet (2003) experiment, these results are still applicable in that selective attention does not lead to qualitative differences in processing, but reduces the influence of distractor elements on the observers' response.

Given the variable refractive error amongst our subjects, it is also important to explore whether attention may differ across those with different types and amounts of refractive error. Whether there were attentional deficits associated with myopia has been previously studied by Turatto et al. (1999) through tasks involving automatic and voluntary orienting of attention, focusing of attention, and performance on a visual search task. While the results by Turatto et al. (1999) showed automatic orienting was defective in myopes, this was only present when myopes had to shift attention to 16 degrees in the periphery; when presented at 8 degrees in the periphery, attention oriented was similar to that of emmetropic

controls (Turrato et al., 1999). Recall our upper and lower visual field stimuli were presented 7 degrees from fixation and, therefore, would not be affected by a deficit in automatic orienting of attention. Although performance was less efficient and slower in myopes than the emmetropic controls, myopes showed no attentional deficits (Turrato et al., 1999). As a result, we do not have to worry about variable refractive error causing attentional deficits and playing a role in the variability of our results.

Lastly, the role of attention should be considered in terms of maintaining attention to the task at hand for the duration of the experiment. A crucial determinant of cognitive performance is the ability to maintain focus of cognitive activity on a given stimulation source or task, and a decrement in sustained attention can be attributed to withdrawal of the attentional system due to underarousal or decreased attentional capacity (Pattyn et al., 2008). Pattyn et al. (2008) evaluated boredom versus cognitive fatigue by monitoring participant performance on a cued conjunction search task while also capturing ECG and respiratory recordings to compute sympathetic and parasympathetic tone. Physiological results supported the underload hypothesis in which vigilance decrements were shown to be associated with things such as mind wandering, and subjective experience of participants was more compatible with boredom rather than high mental effort (Pattyn et al., 2008). During one session of our experiment, subjects completed 1200 trials. Subjects were informed that sessions would be self-paced and they could take breaks as needed. Subjects were told one session would last approximately 1 to 1 ½ hours, which included pre- and post-experiment measurements. Since subjects were asked to complete 1200 trials of the same task in one

sitting, it is possible that attention to the task at hand could have decreased secondary to boredom and affected our psychophysical data.

If decrements in sustained attention occurred over the course of a session of 1200 trials, it is possible that subjects' eyes could have begun to wander along with their minds. There is about a 200-millisecond delay between a target position and the following saccadic eye movement (Purves et. al, 2001), and according to a study by Yao et al. (2016), spatial attention becomes fully allocated to a task-relevant location following a saccade in thirty milliseconds after a saccade. Fortunately, we had a fixation dot that flashed 1.68 milliseconds before each trial to ensure proper fixation when stimuli were presented. However, despite proper fixation, proper attention to the intended location is not guaranteed. Perceptual attention can act independently of saccades in that it is possible to attend to chosen locations or switch attention between locations without moving the eye (Zhao et al., 2012). Studies by Kelley et al. (2008), and Zhang and Golomb (2021) have studied the cortical mechanisms and neural representations of covert attention across saccades while subjects shift and hold attention during fixation. While spatial attention and saccades are often studied independently, the two must work together in order to explore an environment (Zhao et al., 2012). Unfortunately, the dissociation between covert attention and eye movements is not something we have control over, and could have played a role in the variable results obtained if subjects could not sustain attention during the duration of the experiment.

While it is possible that attention could have played a role in our results, it was reassuring to know there are no specific attentional deficits in myopes that could have played a role. However, given the difference in performance between the upper and lower visual

fields, it will be important to investigate whether myopes use their periphery differently than emmetropes or hyperopes.

4.3. Differences in Upper versus Lower Visual Field

Curiously, during our data analysis, we found there was an asymmetry in the performance of the RDK task between the upper and lower visual field, with more subjects being excluded from lower visual field analysis due to failure to complete the task properly. Our decision to present stimuli within 7 degrees of visual eccentricity in the upper and lower visual field in addition to the central visual field was based on several previous studies, including one by Bower, Bian, and Andersen in 2012 that showed there was no consistent effect of eccentricity on global motion discriminations for eccentricities up to 16 degrees. Additionally, since our study was investigating the relationship between motion processing and axial length, we looked into studies regarding differences in the ways myopes use their peripheral visual field compared to those that are emmetropes and hyperopes. Previous studies have shown asymmetries, but in myopic horizontal visual fields rather than in myopic vertical visual fields. This is evident in a study by Atchison, Pritchard, Schmid (2006) which found that myopia has more effect on peripheral refraction along the horizontal visual field than the vertical field, as well as a study by Hathibelagal, Monoharan, and Verkicharla (2022) which found greater asymmetry in flicker modulation thresholds between nasal and temporal visual fields of myopes compared to emmetropes.

Christman (1993) showed that the upper visual field was advantageous for local information processing while the lower visual field was advantageous for global information

processing through two experiments. In the first experiment, sixteen subjects were asked to determine whether a target letter, either E or H, had been presented during a trial of 144 trials; subjects ran through three blocks of experimental trials for a total of 432 trials and the target letter was presented in the left, upper, right, or lower visual field (Christman, 1993). When the target was presented at the global level only, performance in the lower visual field was superior to the upper visual field. When the target was presented at the local level only, performance was better in the upper visual field (Christman, 1993). The second experiment was the same as the first experiment, except the letter E was designated as the target for all subjects; there were 160 trials in each block for a total of 480 trials, and oblique meridians were incorporated as well (Christman, 1993). There was a significant upper visual field advantage for local information but no upper-lower differences in global processing (Christman, 1993). In these experiments, stimuli were presented with their innermost edges at an eccentricity of 2.4 degrees (Christman, 1993). We can see a difference in the results presented by Christman (1993) once oblique meridians were added to the experiment, which may show how variable performance in the visual field can be. In addition, Christman (1993) presented their stimuli at an eccentricity of 2.4 degrees, while we presented our stimuli at 7 degrees eccentricity. Since our stimuli are targeted to evaluate temporal processing as opposed to Christman's (1993) spatial processing, and our stimuli were presented at a further eccentricity, it is possible that performance between the upper and lower visual field varies with different types of stimuli and different eccentricities.

More recent studies investigating differences in the upper and lower visual field have found performance to be better in the lower visual field than in the upper visual field. Zito et

al. (2016) studied the asymmetry in the perception of shapes, orientation, and motion in four visual field quadrants. In the movement task, a pattern of 200 small dots was presented at four degrees of visual eccentricity, with a portion of the dots moving upwards. In contrast, the remaining dots were given displacements spanning 360 degrees to create background noise (Zito et al., 2016). Subjects were asked to decide whether or not the dots were moving coherently upward (Zito et al., 2016). Overall, Zito et al. (2016) found motion perception was more accurate in the lower visual hemifield. While Zito et al. (2016) used a version of RDKs for their experiment, the design still differs greatly from ours, given the task that was asked of the subjects. Subjects in Zito et al. (2016) experiment completed a 2-alternative forced-choice task in which they determined whether the dots that were coherently moving upward were present or not, while we asked subjects in a 4-alternative forced-choice task to determine the overall direction of movement. In addition, our stimulus was presented at 7 degrees visual eccentricity instead of 4 degrees visual eccentricity. There was also a difference in performance over the visual field as a whole, with the orientation task reaching the highest accuracy, followed by the shape task and then the movement task (Zito et al., 2016); this may explain why it was more difficult to obtain reliable results compared to a previous study by Hogue & Taylor (2021), which examined spatial processing within the central visual field.

Levine and McAnany (2005) examined the different visual capabilities within the upper and lower hemifields with different types of stimuli and varying difficulties to test the theory that visual performance is better in the lower visual hemifield due to its association with finer-grained attention. With respect to motion, the three subjects showed a significant

advantage in detecting lateral displacement in the lower visual hemifield (Levine and McAnany, 2005). However, Levine and McAnany (2005) reported that during pilot work, it proved very difficult to test subjects with distractor disks moving laterally in opposite directions from the task region and with target disks steady while other disks moved laterally. Levine and McAnany (2005) could only test subjects with target disks that displaced laterally while other disks remained stationary. Again, while motion processing was examined in the visual field with a variation of RDKs, the design itself is very different from ours based on the goals of our research. As we can see, several factors play a role in visual processing and perception, and Levine and McAnany (2005) suggest that the extent and speed of motion may determine whether detection is better by the magnocellular or parvocellular pathway as well as the upper or lower visual field. As mentioned before, RDK stimuli are very complex and consist of various choices in design based on the task at hand. Performance in the visual field also seems to be very variable based on choices made in the stimulus design.

4.4. Limitations

One limitation is the lack of eye-tracking hardware to ensure subjects looked at the fixation point straight ahead throughout the experiment to ensure fixation stability. To partially address not using an eye tracker, we used a fixation point that flashed before stimuli presentation to attract attention and a brief stimulus duration; the target would disappear if the observer attempted to move their eyes from fixation to the eccentric targets. It is possible that the lifespan of the dots was too short for most naive subjects to appreciate and determine the overall movement of the random dot kinematogram as accurately as experienced subjects.

Subjects were given practice trials before the start of the experiment to ensure they understood the task at hand and to familiarize subjects with the stimulus. Practice trials could be completed as often as needed to ensure the subject understood the task. In retrospect, a strict criterion such that subjects would have to have at least 75% accuracy in the practice trials to move forward to the experiment would have been better than subjectively asking subjects if they feel comfortable moving forward to the experiment after completion of the practice trials.

Finally, as a result of the larger than desired number of subjects having to be excluded from the trial due to poor performance in the experiment, the results may have been underpowered. As mentioned previously, the number of subjects recruited was based on a related task (Hogue & Taylor, 2021) in which a sample size of 30 would provide appropriate statistical power. In future experiments, we may consider recruiting more subjects than the calculated sample size needed for appropriate statistical power to prevent future studies from being underpowered. This is especially true since other studies, like Zi (2016), show that motion tasks are more difficult to obtain accurate results than other tasks, such as spatial or color tasks.

Subject Sample Axial and Population Compared To A Previous Experiment

It is of some concern that, in general, our subjects performed relatively poorly (i.e., they had lower than expected d' when compared with the spatial results and those of experienced observers). One possibility is that the distribution of axial lengths in this sample differed from that used previously. We tested this possibility using a Two-Sample

Komoglorov-Smirnov, which tests whether two sample distributions are drawn from the same underlying population. Using a sample of thirty subjects in a spatial vision experiment (Hogue & Taylor, 2021) revealed no evidence ($D = 0.15$, $p = 0.29$) that our data were drawn from different populations. The first and second moments of the sample distribution, the mean (24.76 mm), and standard deviation (1.59 mm) were very similar to a previous experiment, but the data range (20.91 to 27.88 mm) differed, as did the skewness (-0.18).

4.5. Conclusion and Future Directions

There was no significant difference in performance with ON versus OFF RDK stimuli in the central visual field, upper visual field, and lower visual field. The results remain true even while accounting for axial length. Performance in both ON and OFF RDK stimuli remains relatively unchanged regardless of axial length, with only a slight decrease in performance with increasing axial length.

Although there were no significant results to report from our study, it helps to pave the way for future studies. Through this experience, we can reflect on the limitations of our study design and do our best to combat these limitations in future studies. In addition, data obtained from this study may open up research for future studies similar to when Manning, Meier, and Giachi (2022) studied reverse motion illusion and believed it could be an under-reported phenomenon since participants experiencing such a phenomenon would be a minority and excluded from the analysis.

Bibliography

Ang BCH, Cheong KX, Tan MMH, et al. Correlation of myopia severity with visual performance. *Int Ophthalmol*. 2020;40(9):2201-2211. doi:10.1007/s10792-020-01403-7

Anstis S, Verstraten FA, Mather G. The motion aftereffect. Trends Cogn Sci. 1998 Mar 1;2(3):111-7. doi: 10.1016/s1364-6613(98)01142-5. PMID: 21227087.

Aleman AC, Wang M, Schaeffel F. Reading and Myopia: Contrast Polarity Matters. *Sci Rep*. 2018;8(1):1-8. doi:10.1038/s41598-018-28904-x

Atchison DA, Pritchard N, Schmid KL. Peripheral refraction along the horizontal and vertical visual fields in myopia. *Vision Res*. 2006;46(8-9):1450-1458. doi:10.1016/j.visres.2005.10.023

Atchison DA, Schmid KL, Pritchard N. Neural and optical limits to visual performance in myopia. *Vision Res*. 2006;46(21):3707-3722. doi:10.1016/j.visres.2006.05.005

Atkinson J, Anker S, Bobier W, et al. Normal emmetropization in infants with spectacle correction for hyperopia. *Invest Ophthalmol Vis Sci*. 2000;41(12):3726-3731.

Bae GY, Luck SJ. Perception of opposite-direction motion in random dot kinematograms. Vis cogn. 2022;30(4):289-303. doi: 10.1080/13506285.2022.2052216. Epub 2022 Mar 14. PMID: 35800036; PMCID: PMC9255862.

Bennett PJ, Sekuler AB, Ozin L. Effects of aging on calculation efficiency and equivalent noise. *J Opt Soc Am A Opt Image Sci Vis*. 1999;16(3):654-668. doi:10.1364/josaa.16.000654

Bex, P. J., & Dakin, S. C. (2003). Motion detection and the coincidence of structure at high and low spatial frequencies. Vision Research, 43(4), 371-383.

Bex, P.J. Personal communication. April 19, 2023.

Bower JD, Bian Z, Andersen GJ. Effects of retinal eccentricity and acuity on global-motion processing. *Atten Percept Psychophys*. 2012;74(5):942-949. doi:10.3758/s13414-012-0283-2

Carney LG, Mainstone JC, Henderson BA. Corneal topography and myopia. A cross-sectional study. *Invest Ophthalmol Vis Sci*. 1997;38(2):311-320.

Carrasco M, McElree B, Denisova K, Giordano AM. Speed of visual processing increases with eccentricity [published correction appears in Nat Neurosci. 2003 Aug;6(8):899]. *Nat Neurosci*. 2003;6(7):699-700. doi:10.1038/nn1079

Chakraborty R, Read SA, Collins MJ. Diurnal variations in axial length, choroidal thickness, intraocular pressure, and ocular biometrics. *Invest Ophthalmol Vis Sci*. 2011;52(8):5121-5129. Published 2011 Jul 11. doi:10.1167/iovs.11-7364

Christman, SD. Local-global processing in the upper versus lower visual fields. *Bull. Psychon. Soc.* 1993;31, 275-278. doi:10.3758/BF03334927

Cremieux J, Orban GA, Duysens J, Amblard B, Kennedy H. Experimental myopia in cats reared in stroboscopic illumination. *Vision Res*. 1989;29(8):1033-1036. doi:10.1016/0042-6989(89)90117-x

Czepita M, Czepita D, Safranow K. Role of Gender in the Prevalence of Myopia among Polish Schoolchildren. *J Ophthalmol*. 2019;2019:9748576. Published 2019 Jul 2. doi:10.1155/2019/9748576

Dolgin E. The myopia boom. *Nature*. 2015;519(7543):276-278. doi:10.1038/519276a

Ehsaei A, Chisholm CM, Pacey IE, Mallen EAH. Visual performance fall-off with eccentricity in myopes versus emmetropes [Disminución del rendimiento visual con la excentricidad en pacientes miopes frente a emétropes]. *J Optom*. 2013;6(1):36-44. doi:10.1016/j.optom.2012.07.001

Falkenberg HK, Simpson WA, Dutton GN. Development of sampling efficiency and internal noise in motion detection and discrimination in school-aged children. *Vision Res*. 2014;100:8-17. doi:10.1016/j.visres.2014.04.001

Flitcroft DI, He M, Jonas JB, et al. IMI - Defining and Classifying Myopia: A Proposed Set of Standards for Clinical and Epidemiologic Studies. *Invest Ophthalmol Vis Sci*. 2019;60(3):M20-M30. doi:10.1167/iovs.18-25957

Green, M. L., & Pratte, M. S. (2020). Access to sensory uncertainty in global motion perception depends on the stimulus. Journal of Vision, 20(11), 1513.

Grosvenor T, Goss DA. Role of the cornea in emmetropia and myopia. *Optom Vis Sci*. 1998;75(2):132-145. doi:10.1097/00006324-199802000-00017

Haarman AEG, Enthoven CA, Tideman JWL, Tedja MS, Verhoeven VJM, Klaver CCW. The Complications of Myopia: A Review and Meta-Analysis. *Invest Ophthalmol Vis Sci*. 2020;61(4):49. doi:10.1167/iovs.61.4.49

Hathibelagal AR, Manoharan MK, Verkicharla PK. Do myopes have deficits in peripheral flicker sensitivity?. *J Optom*. 2022;15(2):138-144. doi:10.1016/j.optom.2021.01.003

Hogue W, Taylor CP. Axial length is associated with individual differences in ON- and OFF-pattern detection. *Invest. Ophthalmol. Vis. Sci.* 2021;62(8):2894.

Hoseini-Yazdi H, Vincent SJ, Collins MJ, Read SA. Regional alterations in human choroidal thickness in response to short-term monocular hemifield myopic defocus. *Ophthalmic Physiol Opt*. 2019;39(3):172-182. doi:10.1111/opo.12609

Hoseini-Yazdi H, Read SA, Alonso-Caneiro D, Collins MJ. Retinal OFF-Pathway Overstimulation Leads to Greater Accommodation-Induced Choroidal Thinning. *Invest Ophthalmol Vis Sci*. 2021;62(13):5. doi:10.1167/iovs.62.13.5

Hyman L, Gwiazda J, Hussein M, et al. Relationship of age, sex, and ethnicity with myopia progression and axial elongation in the correction of myopia evaluation trial. *Arch Ophthalmol*. 2005;123(7):977-987. doi:10.1001/archopht.123.7.977

Jaworski A, Gentle A, Zele AJ, Vingrys AJ, McBrien NA. Altered visual sensitivity in axial high myopia: a local postreceptoral phenomenon?. *Invest Ophthalmol Vis Sci*. 2006;47(8):3695-3702. doi:10.1167/iovs.05-1569

Ji LJ, Yap S, Best MW, McGeorge K. Global Processing Makes People Happier Than Local Processing. *Front Psychol*. 2019;10:670. Published 2019 Mar 26. doi:10.3389/fpsyg.2019.00670

Jiang X, Tarczy-Hornoch K, Cotter SA, et al. Association of Parental Myopia With Higher Risk of Myopia Among Multiethnic Children Before School Age. *JAMA Ophthalmol*. 2020;138(5):501-509. doi:10.1001/jamaophthalmol.2020.0412

Jonas JB, Ohno-Matsui K, Panda-Jonas S. Myopia: Anatomic Changes and Consequences for Its Etiology. *Asia Pac J Ophthalmol (Phila)*. 2019;8(5):355-359. doi:10.1097/01.APO.0000578944.25956.8b

Jones-Jordan LA, Sinnott LT, Chu RH, et al. Myopia Progression as a Function of Sex, Age, and Ethnicity. *Invest Ophthalmol Vis Sci*. 2021;62(10):36. doi:10.1167/iovs.62.10.36

Kelley TA, Serences JT, Giesbrecht B, Yantis S. Cortical mechanisms for shifting and holding visuospatial attention. *Cereb Cortex*. 2008;18(1):114-125. doi:10.1093/cercor/bhm036

Kerber KL, Thorn F, Bex PJ, Vera-Diaz FA. Peripheral contrast sensitivity and attention in myopia. *Vision Res*. 2016;125:49-54. doi:10.1016/j.visres.2016.05.004

Kuo HY, Atchison DA, Schmid KL. Dot Motion Perception in Young Adult Emmetropes and Myopes. *Optom Vis Sci*. 2018;95(6):498-504. doi:10.1097/OPX.0000000000001223

Lanca C, Yam JC, Jiang WJ, et al. Near work, screen time, outdoor time and myopia in schoolchildren in the Sunflower Myopia AEEC Consortium. *Acta Ophthalmol*. 2022;100(3):302-311. doi:10.1111/aos.14942

Levine MW, McAnany JJ. The relative capabilities of the upper and lower visual hemifields. *Vision Res*. 2005;45(21):2820-2830. doi:10.1016/j.visres.2005.04.001

Lin G, Taylor C, Rucker F. Effect of duration, and temporal modulation, of monochromatic light on emmetropization in chicks. *Vision Res*. 2020;166:12-19. doi:10.1016/j.visres.2019.11.002

Liang CL, Yen E, Su JY, et al. Impact of family history of high myopia on level and onset of myopia. *Invest Ophthalmol Vis Sci*. 2004;45(10):3446-3452. doi:10.1167/iovs.03-1058

Macmillan NA, Creelman CD. Detection theory: A user's guide. Psychology press; 2004 Sep 22

Manning C, Dakin SC, Tibber MS, Pellicano E. Averaging, not internal noise, limits the development of coherent motion processing. *Dev Cogn Neurosci*. 2014;10:44-56. doi:10.1016/j.dcn.2014.07.004

Manning C, Meier K, Giaschi D. The reverse motion illusion in random dot motion displays and implications for understanding development. J Illusion. 2022 Jan 10;3:7916. doi: 10.47691/joi.v3.7916. PMID: 35111989; PMCID: PMC7612299.

Mazade R, Jin J, Pons C, Alonso JM. Functional Specialization of ON and OFF Cortical Pathways for Global-Slow and Local-Fast Vision. *Cell Rep*. 2019;27(10):2881-2894.e5. doi:10.1016/j.celrep.2019.05.007

Meng W, Butterworth J, Malecaze F, Calvas P. Axial length of myopia: a review of current research. *Ophthalmologica*. 2011;225(3):127-134. doi:10.1159/000317072

Modjtahedi BS, Ferris FL 3rd, Hunter DG, Fong DS. Public Health Burden and Potential Interventions for Myopia. *Ophthalmology*. 2018;125(5):628-630. doi:10.1016/j.ophtha.2018.01.033

Murray RF, Sekuler AB, Bennett PJ. A linear cue combination framework for understanding selective attention. *J Vis*. 2003;3(2):116-145. doi:10.1167/3.2.2

Narasimhan S, Giaschi D. The effect of dot speed and density on the development of global motion perception. *Vision Res*. 2012;62:102-107. doi:10.1016/j.visres.2012.02.016

Nayar K, Franchak J, Adolph K, Kiorpes L. From local to global processing: the development of illusory contour perception [published correction appears in J Exp Child Psychol. 2015 Jul;135:102]. *J Exp Child Psychol*. 2015;131:38-55. doi:10.1016/j.jecp.2014.11.001

Nickla DL, Wallman J. The multifunctional choroid. *Prog Retin Eye Res*. 2010;29(2):144-168. doi:10.1016/j.preteyeres.2009.12.002

Nishida S, Kawabe T, Sawayama M, Fukiage T. Motion Perception: From Detection to Interpretation. *Annu Rev Vis Sci*. 2018;4:501-523. doi:10.1146/annurev-vision-091517-034328

Pandarinath C, Victor JD, Nirenberg S. Symmetry breakdown in the ON and OFF pathways of the retina at night: functional implications. *J Neurosci*. 2010;30(30):10006-10014. doi:10.1523/JNEUROSCI.5616-09.2010

Pardhan S, Gilchrist J, Elliott DB, Beh GK. A comparison of sampling efficiency and internal noise level in young and old subjects. *Vision Res*. 1996;36(11):1641-1648. doi:10.1016/0042-6989(95)00214-6

Pattyn N, Neyt X, Henderickx D, Soetens E. Psychophysiological investigation of vigilance decrement: boredom or cognitive fatigue?. *Physiol Behav*. 2008;93(1-2):369-378. doi:10.1016/j.physbeh.2007.09.016

Pilly PK, Seitz AR. What a difference a parameter makes: a psychophysical comparison of random dot motion algorithms. *Vision Res*. 2009;49(13):1599-1612. doi:10.1016/j.visres.2009.03.019

Purves D, Augustine GJ, Fitzpatrick D, et al., editors. Neuroscience. 2nd edition. Sunderland (MA): Sinauer Associates; 2001. Types of Eye Movements and Their Functions. Available from: https://www.ncbi.nlm.nih.gov/books/NBK10991/

Ravi S, Ahn D, Greschner M, Chichilnisky EJ, Field GD. Pathway-Specific Asymmetries between ON and OFF Visual Signals. *J Neurosci*. 2018;38(45):9728-9740. doi:10.1523/JNEUROSCI.2008-18.2018

Schaeffel F, Feldkaemper M. Animal models in myopia research. *Clin Exp Optom*. 2015;98(6):507-517. doi:10.1111/cxo.12312

Simpson WA, Falkenberg HK, Manahilov V. Sampling efficiency and internal noise for motion detection, discrimination, and summation. *Vision Res*. 2003;43(20):2125-2132. doi:10.1016/s0042-6989(03)00336-5

Stoimenova BD. The effect of myopia on contrast thresholds. *Invest Ophthalmol Vis Sci*. 2007;48(5):2371-2374. doi:10.1167/iovs.05-1377

Summers JA. The choroid as a sclera growth regulator. *Exp Eye Res*. 2013;114:120-127. doi:10.1016/j.exer.2013.03.008

Tan CS, Ouyang Y, Ruiz H, Sadda SR. Diurnal variation of choroidal thickness in normal, healthy subjects measured by spectral domain optical coherence tomography. *Invest Ophthalmol Vis Sci*. 2012;53(1):261-266. Published 2012 Jan 25. doi:10.1167/iovs.11-8782

Tian T, Zou L, Wu S, Liu H, Liu R. Wavelength Defocus and Temporal Sensitivity Affect Refractive Development in Guinea Pigs. *Invest Ophthalmol Vis Sci*. 2019;60(6):2173-2180. doi:10.1167/iovs.18-25228

Turatto M, Facoetti A, Serra G, et al. Visuospatial attention in myopia. *Brain Res Cogn Brain Res*. 1999;8(3):369-372. doi:10.1016/s0926-6410(99)00025-7

van der Smagt MJ, van de Grind WA. Integration and segregation of local motion signals: the role of contrast polarity. *Vision Res*. 1999;39(4):811-822. doi:10.1016/s0042-6989(98)00133-3

Walline JJ. Myopia Control: A Review. *Eye Contact Lens*. 2016;42(1):3-8. doi:10.1097/ICL.0000000000000207

Wallman J, Wildsoet C, Xu A, et al. Moving the retina: choroidal modulation of refractive state. *Vision Res*. 1995;35(1):37-50. doi:10.1016/0042-6989(94)e0049-q

Wang D, Chun RK, Liu M, et al. Optical Defocus Rapidly Changes Choroidal Thickness in Schoolchildren. *PLoS One*. 2016;11(8):e0161535. Published 2016 Aug 18. doi:10.1371/journal.pone.0161535

Wang J, Li Y, Musch DC, et al. Progression of Myopia in School-Aged Children After COVID-19 Home Confinement. *JAMA Ophthalmol*. 2021;139(3):293-300. doi:10.1001/jamaophthalmol.2020.6239

Wei J, Kong D, Yu X, et al. Is Peripheral Motion Detection Affected by Myopia?. *Front Neurosci*. 2021;15:683153. Published 2021 Jun 7. doi:10.3389/fnins.2021.683153

Wu X, Spering M. Tracking and perceiving diverse motion signals: Directional biases in human smooth pursuit and perception. *PLoS One*. 2022;17(9):e0275324. Published 2022 Sep 29. doi:10.1371/journal.pone.0275324

Xu R, Zhong P, Jan C, et al. Sex Disparity in Myopia Explained by Puberty Among Chinese Adolescents From 1995 to 2014: A Nationwide Cross-Sectional Study. *Front. Public Health* . 2022. Published 2022 May 30. doi: 10.3389/fpubh.2022.833960

Yao T, Ketkar M, Treue S, Krishna BS. Visual attention is available at a task-relevant location rapidly after a saccade. *Elife*. 2016;5:e18009. Published 2016 Nov 23. doi:10.7554/eLife.18009

Zhang X, Golomb JD. Neural Representations of Covert Attention across Saccades: Comparing Pattern Similarity to Shifting and Holding Attention during Fixation. *eNeuro*. 2021;8(2):ENEURO.0186-20.2021. Published 2021 Apr 5. doi:10.1523/ENEURO.0186-20.2021

Zhao M, Gersch TM, Schnitzer BS, Dosher BA, Kowler E. Eye movements and attention: the role of pre-saccadic shifts of attention in perception, memory and the control of saccades. *Vision Res*. 2012;74:40-60. doi:10.1016/j.visres.2012.06.017

Zito GA, Cazzoli D, Müri RM, Mosimann UP, Nef T. Behavioral Differences in the Upper and Lower Visual Hemifields in Shape and Motion Perception. *Front Behav Neurosci*. 2016;10:128. Published 2016 Jun 17. doi:10.3389/fnbeh.2016.00128

Supplemental Material

Participant Questionnaire

Participant Questionnaire

New England College of Optometry

Name: _____

Age: _____

Gender: □M □ F □ Other

Date of last eye exam:_____

History of ocular diseases (e.g. glaucoma, eye infections, dry eye):

_____

_____

Approximate age when prescribed glasses (if applicable): _____

Does your father require correction to see far away? (e.g. glasses, contacts, lasik): □Y □ N

Does your mother require correction to see far away? (e.g. glasses, contacts, lasik): □Y □ N

Estimated time spent awake per day:_____

Estimated time spent asleep per day:_____

Estimated amount of caffeine consumed in the past 24 hours:_____

Estimated number of hours spent reading/studying per day:_____

Would you be interested in participating in future experiments? □Y □ N

Email (if yes to above):_____

Table 2. Demographics

Subject	Sex	Age	Myopia Age	Axial OD	Sphere OD	Cyl OD	Axis OD	SE OD	Axial OS	Sphere OS	Cyl OS	Axis OS	SE OS
1	F	23	7	25.69	-5.25	-0.75	174	-5.625	25.74	-5.75	-0.75	17	-6.125
2	F	23	9	25.87	-4.25	-0.25	11	-4.375	25.51	-3.50	-0.75	8	-3.875
3	F	23	15	24.32	-3.50	-0.25	144	-3.625	24.12	-3.50	-0.25	85	-3.625
4	F	24	7	26.35	-7.00	-2.00	179	-8.000	25.46	-5.25	-1.00	6	-5.750
5	F	24	12	24.69	-3.50	-1.75	91	-4.375	24.92	-4.00	-1.50	89	-4.750
6	F	25	12	24.27	-4.50	-0.25	28	-4.625	24.36	-4.00	-0.25	122	-4.125
7	F	23	8	24.85	-3.75	-0.50	176	-4.000	24.83	-3.75	-0.50	10	-4.000
8	M	25	3	27.08	-8.25	-1.50	160	-9.000	26.64	-7.75	-1.25	176	-8.375
9	M	24	10	23.92	-2.75	-0.25	160	-2.875	23.86	-3.00	-0.25	40	-3.125
10	F	24	N/A	23.09	-1.00	0.00	0	-1.000	22.88	-1.25	-0.25	149	-1.375
11	F	24	7	26.44	-6.00	-2.25	7	-7.125	26.73	-6.25	-2.25	10	-7.375
12	F	27	22	23.02	-1.75	-0.25	174	-1.875	23.03	-2.00	0.00	0	-2.000
13	F	31	N/A	23.50	0.00	-0.50	12	-0.250	23.46	-0.25	-0.25	24	-0.375
14	F	25	N/A	22.87	0.50	-0.25	174	0.375	22.98	0.50	-0.50	15	0.250
15	F	24	10	25.46	-4.00	-0.50	8	-4.250	25.32	-3.00	-0.25	161	-3.125
16	F	25	14	24.36	-2.00	0.25	156	-1.875	24.23	-1.75	0.00	0	-1.750
17	F	23	N/A	24.29	-0.50	-0.25	133	-0.625	24.31	-1.25	-0.75	11	-1.625
18	M	36	12	25.01	0.50	-2.50	91	-0.750	24.81	0.75	-1.25	78	0.125
19	M	36	12	23.64	-0.50	-0.50	18	-0.750	23.64	-0.75	-1.00	175	-1.250
20	F	23	9	23.89	-3.00	-0.25	15	-3.125	23.10	-1.50	0.00	0	-1.500
21	M	23	15	24.56	-2.00	-0.50	165	-2.250	24.60	-2.00	-0.75	172	-2.375
22	M	23	N/A	24.88	0.75	-0.75	173	0.375	24.81	1.00	-0.75	10	0.625
23	F	24	7	27.28	-5.25	-2.75	1	-6.625	27.03	-5.00	-2.25	180	-6.125
24	F	23	10	27.06	-7.50	-0.25	24	-7.625	26.16	-5.25	-0.75	157	-5.625
25	F	24	15	25.08	-1.25	-0.25	168	-1.375	25.11	-1.25	0.00	0	-1.250
26	F	24	N/A	22.39	0.25	-0.25	12	0.125	22.27	-0.25	-0.25	153	-0.375
27	F	36	N/A	22.22	0.50	-0.25	133	0.375	22.43	0.50	0.00	0	0.500
28	F	22	12	24.67	-2.75	0.00	0	-2.750	24.76	-2.75	-0.25	164	-2.875
29	M	25	8	28.24	-4.00	-0.75	75	-4.375	28.10	-3.75	-1.00	100	-4.250
30	F	25	12	24.30	-1.25	0.00	0	-1.250	24.64	-1.75	-0.25	10	-1.875