Eye Dominance in Young Adults with Symptoms and/or Signs of Binocular Visual Dysfunctions

Thesis

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By

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Abstract

Eye dominance is the preferential use of one eye over its companion to perform any given task. Eye dominance can broadly be classified into motor eye dominance (MED), also known as sighting dominance, and sensory eye dominance (SED), the eye with which an individual perceives more during binocular vision. However, it is not well understood how eye dominance affects the ability to accommodate in individuals with binocular vision dysfunction. Thus, the purpose of this study was to measure the accommodative responses of the dominant and non-dominant eye under different accommodative testing conditions using the Grand Seiko WAM-5500 Autorefractor. These accommodative test conditions were binocular, direct, and consensual. This study consisted of two visits, the first determining the clinical binocular status and symptoms of subjects. If subjects were determined to have binocular vision dysfunction based on clinical signs and/or symptoms, MED, SED, and accuracy of accommodation were assessed at the second visit. We found similar accuracy of accommodation between dominant and non-dominant eyes at all test conditions, but a significantly increased lag of accommodation in the consensual test condition compared to both binocular and direct conditions. This led us to conclude that accuracy of accommodation is not dependent on dominance of the eye, but whether the eye is viewing the target.

Dedication

This thesis is dedicated to my husband, Thomas, who has constantly supported me through the stresses of life, optometry school, thesis work, and the balance of all three. Words cannot express how thankful I am for your words of encouragement and reminders of the final product of this work. This work is also dedicated to my parents, Brent and Susan Smith, who have always encouraged me to be resilient and persistent until I have attained my goals. I am blessed to be your daughter and I cannot thank you both enough.

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Chapter 1. Introduction

1.1 Eye Dominance

Eye dominance is the preference of one eye above its partner for visual tasks. It is not uncommon for an individual to prefer one of a pair of bilateral members within the body. This is seen in writing as well as kicking a ball. As with handedness, eye dominance can be a natural occurrence in addition to a trained phenomenon, depending on individual experience (Porac & Coren, 1976). Typically, eye dominance is determined subconsciously by the viewer. Even so, if there is a visual defect in the naturally preferred dominant eye, the individual may train themselves to utilize the opposite eye as dominant.

Eye dominance can be dependent on the task performed. There are varying types of eye dominance an individual maintains. Acuity dominance is where the observer prefers the use of one eye due to the improved quality of vision in that eye. Motor eye dominance (MED) is where the observer prefers one eye over the other when sighting. Sensory eye dominance (SED) is where the observer utilizes the eye that perceives more. SED tends to be less noticeable to an individual, therefore one may not notice a difference in perception between eyes (Ooi & He, 2020). MED and SED can be the opposite of one another, though the reasoning for this is not well understood.

1.11 Sensory Eye Dominance

As previously mentioned, SED is determined to be the eye a person perceives most with. This mechanism is not well understood. It is believed that SED may be caused by an interocular imbalance of inhibition and/or integration revealed between the two eyes (Han et al., 2019). Even so, this imbalance of inhibition or integration can switch between the two eyes (Deiter et al., 2017). The eye that is suppressed the least number of times, or requires less stimulus strength to integrate, is thought to be the preferred-looking eye (Ehrenstein et al., 2005). Two methods used most often to determine SED are blur tolerance and binocular rivalry.

Practitioners test SED by looking for monocular blur tolerance. This procedure is often performed when determining an individual's dominant eye for multifocal contact lens or monovision. In a binocular setting, plus lenses are placed in front of one eye until blur is reported by the patient (Lopes-Ferreira et al., 2013). Whichever eye tolerates the least amount of plus lenses is said to be the SED eye.

One's SED can also be determined using a binocular rivalry technique. This is where dichoptic stimuli with non-identical patterns are presented to determine which eye predominates during binocular rivalry.   It is assumed that SED may drive the first (predominant) perceptions of binocular rivalry (Dieter et al., 2017). The binocular imbalance between the two stimuli leads an individual to see more of the stimulus presented to the SED eye. To reduce rivalry alteration between the two dichoptic stimuli, the presentation is only milliseconds in length (Bossi, et al. 2018). The magnitude of SED can be measured by attempting to balance the stimulus strengths of the dichoptic stimuli using a psychophysical method, such as the QUEST procedure (Ooi & He, 2020). The QUEST procedure is a psychometric procedure that places each trial at the current most probable Bayesian estimate of threshold (Watson & Pelli, 1983). At the conclusion of this method, a balance point (i.e., in stimulus contrast or luminance) is found between the two eyes.

1.12 Motor Eye Dominance

MED refers to sighting dominance. This is the eye that one uses for sighting (Ho et al., 2018). The MED is most recognizably used in shooting sports. Though handedness may play a role in the side an individual wields the instrument, MED impacts accuracy of the athlete's shots. There are other such activities that depend upon MED, such as sighting a camera or looking through a monocular microscope/telescope (Sköldsson, 2019). The eye that sights most accurately is necessary to view appropriately through these devices.

MED is often determined with a sighting test, such as the hole-in-hand test. Figure 1 demonstrates that this procedure includes an individual holding some type of aperture, such as their two hands crossing to form a triangle shape in the center. The aperture is held in such a way that the individual sights the target with both eyes open. Whichever eye is still viewing the target when the fellow is covered is the MED. In similar fashion, the aperture can be used to sight another's eye and the MED is the eye seen through the opening (Ho et al., 2018).

It has been proposed that saccadic peak velocities could determine the magnitude of eye dominance. The frontal eye fields that control saccadic eye movements are in the contralateral frontal lobe of the brain from the viewing eye. Chaumillon et al. (2017) suggests that whichever eye reaches peak saccadic velocity quicker is the MED eye. If there is a greater difference in the velocities of the saccades between the MED dominant and non-dominant eyes, the MED is deemed to be stronger (Tagu et al., 2018). It can also be seen that the MED eye can more easily locate the target at the completion of the saccade (Tagu et al., 2016). Essentially, the MED eye would have the fastest reaction time and be most accurate when finding the target.

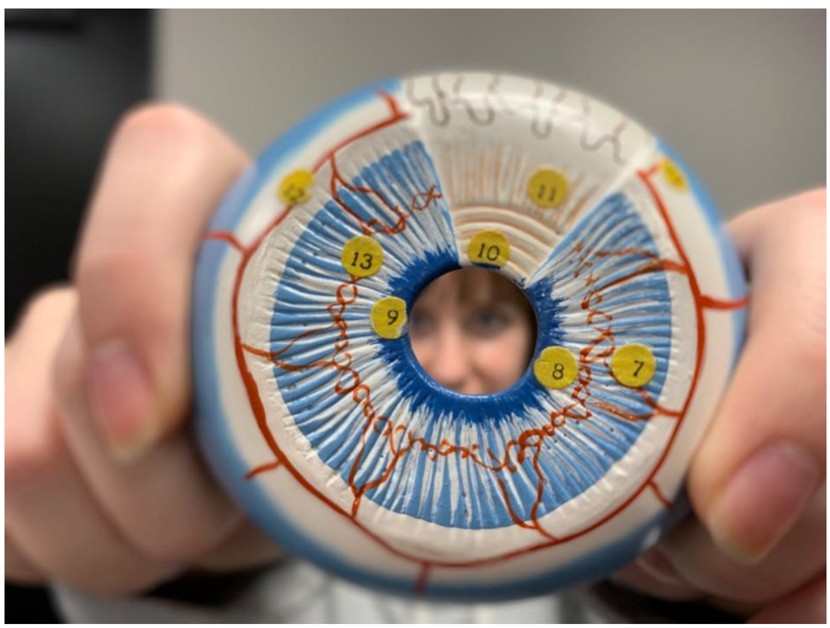

Figure 1 Motor eye dominance determination with aperture

This test demonstrates left MED as subject's left eye is most centered in the aperture.

Handedness and MED are not always the same. One could have MED of the left eye but be right-handed. The opposite combination could also be true. Even so, it is common for one to have MED and handedness be the same side (Sköldsson, 2019). It has been thought that when MED and handedness are the same, an individual is more likely to have pseudo-neglect of the opposite hemisphere of vision, producing a preference of the dominant hemisphere (Schintu et al., 2020). Consequently, the combination of MED and handedness allows for an individual to obtain a more wholistic concept of one's visual environment.

1.13 Conflict Between SED and MED

While both SED and MED can be determined independently, it has been found that the results do not always agree. A correlation between MED and SED has not been found (Deiter et al., 2017). MED has not been found to correspond with the visual function imbalance between the eyes (Han et al., 2018). Therefore, an individual eye may be both MED and SED. Inversely, one eye may be MED alone while the companion is SED alone.

1.2 Importance of Eye Dominance

As previously mentioned, both SED and MED are a significant consideration in multiple situations, though MED is more widely exploited. Athletes utilize their MED eye to track projectiles, such as a ball or puck, or aim at goals/targets. SED and MED can be used clinically in contact lens fittings, while MED is often employed while designing and fitting Bioptic telescope systems.

1.21 Eye Dominance in Athletes

In athletics, eye dominance has been most closely studied with shooting sports. But paradoxically, when studied, it was found that accuracy of shooting was not dependent on which eye was dominant. It is also not imperative that an individual share handedness and eye dominance on the same side (Nosek et al., 2018). Even so, individuals with crossed dominance, having opposite hand and eye dominances, may need more training to determine what posture is most appropriate (Jones et al., 1996).

Other sports also use eye dominance on the court. Tennis players hit the ball more accurately when their dominant eye is closest to the projectile and using the contralateral hand to wield the racket (Ziagkas et al., 2017). Baseball players whose handedness is opposite to their dominant eye (i.e., right-handed but left eye dominant) have been seen to be more successful at-bat (Portal & Romano, 1998). These examples demonstrate that eye dominance has a role in a variety of sports.

1.22 Clinical Implications of Eye Dominance

Monovision or multifocal contact lenses, as mentioned before, are how clinicians most commonly use eye dominance tests, whether sighting or blur tolerance. If the dominant eye were to be the “near” eye or the eye with the most powerful add, the patient may complain of blurred vision at distance. Distance vision is deemed more of a priority in these instances due to the importance of vision for distance tasks, such as driving, and that the non-dominant eye is more likely to be suppressed (Zheleznyak et al., 2015). While this is true in some cases, Van Severen, et al. (2021) determined that the success of monovision contacts is most dependent on the binocular vision status of the individual and not directly reliant on whether the dominant eye is set for distance or near viewing. It was found that individuals did not have a preference to monovision correction of the dominant and non-dominant eyes; those individuals with clinically normal stereoacuity were more likely to be content with any monovision correction as compared to those with poor or no stereoacuity (Van Severen, et al., 2021). Separately, it has been found success of monovision is often determined by the magnitude of eye dominance in that individuals with larger eye dominances are often less satisfied in a monovision-type visual correction (Zheleznyak et al., 2015). MED and SED have individually been tested clinically to determine appropriate lens powers, with both techniques resulting in patient satisfaction (Evans, 2007).

Another such instance that one may use eye dominance in the clinical setting is with Bioptic telescope systems. When an individual uses a Bioptic telescope, the dominant eye views through the ocular. As the dominant eye is sighting through the telescope, dominance is most often based on visual acuity or MED. The fellow eye is often, though not always, occluded by the telescope system (Greene, 2018). Therefore, it is necessary that the dominant eye be determined appropriately for comfort and safety of the individual.

1.3 Binocular Vision Dysfunction

In an individual with normal binocular vision, the convergent and divergent eye movements accurately focus targets at infinity as well as near. These eye movements are controlled by stimuli created by proximity of target, blur, and disparity of a target. There is a certain amount of tonic vergence an individual possesses that drives these movements as well (Fisher et al., 1988). A combination of these four stimuli drive the vergence system.

Binocular vision dysfunction is an umbrella term encompassing any binocular vision disorder. Individuals afflicted with these disorders can present with a wide range of symptoms including blurred vision, asthenopia, diplopia, frontal headaches, and difficulty reading or performing close work. Uncorrected refractive error could present with symptoms similar to binocular vision disorders, therefore, it is necessary for clinicians to appropriately correct refractive error prior to diagnosis (Yekta et al., 2017). Some disorders create a larger concern at distance than near, or vice versa. Others have equal impact at both distance and near.

The binocular vision status of an individual can be determined clinically with various procedures, such as cover test, compensating vergence ranges, vergence facility, and near point of convergence (NPC). Eye posture is evaluated with a cover test procedure. Figure 2 demonstrates eye movements seen on unilateral and alternate cover tests. A unilateral cover test determines if a strabismus is present. On alternate cover test, a phoria can be discovered if strabismus is not present. In the presence of either strabismus or phoria, magnitude can be determined by neutralizing with prism (Mestre et al., 2018).

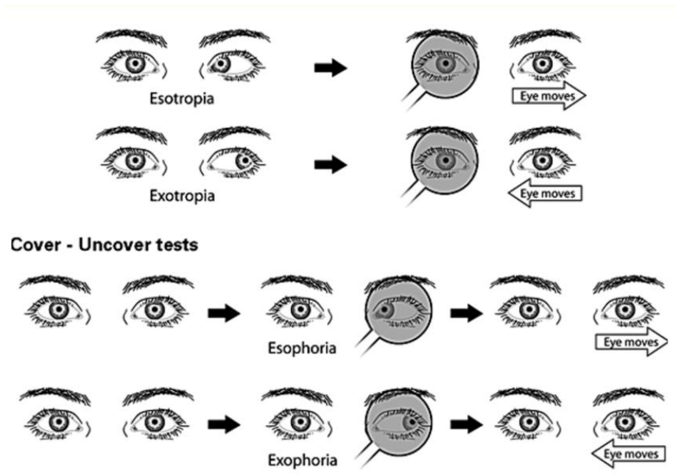

Figure 2 Unilateral and alternate cover test taken from Acta Scientific Ophthalmology, 2021

Vergence ranges can be measured both with and without the phoropter. If measured with the phoropter, smooth vergence ranges are determined with a Risley prism in both base-in (negative fusional vergence) and base-out (positive fusional vergence) directions. If measured without the phoropter, stepwise prism bars are used to measure in base-in and base-out directions. Individuals are asked to verbally indicate the blur, break, and recovery points. The blur point is then compared to the neutralizing prism found during cover test. Sheard's criterion recommends that the blur point of the compensating vergence range be at least twice the value of the deviation, whereas Percival's criterion recommends that the deviation falls in the middle third of vergence ranges (Moon, et al., 2020). Failure to meet these criteria likely correlates with symptoms in affected individuals (Dalziel, 1981).

In order to test the flexibility of the vergence system, vergence facility can be performed clinically. This is often done with alternating base-in and base-out prisms. Individuals are asked to fuse a target through one prism base before exchanging it for the other base. Difficulty clearing base-in prism indicates reduced negative fusional vergence, while impeded ability to clear base-out prism indicates reduced positive fusional vergence. Those individuals with reduced ability to perform this task have signs of binocular vision dysfunction (Gall, et al., 1998).

NPC is assessed by asking an individual to converge the eyes as a target is brought closer. The break value is either when the individual reports diplopia or an eye turn is noted by the examiner. Recovery from the break value is also recorded. If NPC range is large, it implies reduced positive fusional vergence and is indicative of the presence of a binocular vision disorder (Hamed, et al. 2013).

1.31 Divergence Excess

Divergence excess presents with an exodeviation that is greater when looking at infinity than a near target. Prevalence of divergence excess is low, affecting 0.03% of the population (Cooper, 2020). True to the name “excess,” the accommodative convergence/accommodation (AC/A) ratio is elevated compared to clinically normal patients. Individuals with divergence excess may complain of cosmetic concerns associated with the eye posture (Flax, 2018). One may also complain of sensitivity to bright lights to the extent of requiring one eye to be occluded (Srinivasan, 2017). Positive fusional vergence will be reduced at distance. Due to the elevated AC/A ratio, affected individuals respond well to minus lenses for distance to reduce the exodeviation posture (Cooper, 2018).

1.32 Divergence Insufficiency

If an individual suffers from divergence insufficiency, there is an esodeviation that is larger at distance than near (Brune & Eggenberger, 2018). Little research has been performed on its prevalence. One study quotes only 0.10% of the population is affected, though it was performed over twenty years ago (Cooper, 2020). The AC/A ratio is reduced from normal in this condition. Afflicted individuals will have difficulty with negative fusional vergence at infinity, so base-in ranges will be reduced during clinical binocular testing. These individuals can have diplopia at distance that is intermittent. This diplopia may lessen following rest from distance viewing. The most effective treatment for individuals with divergence insufficiency is base-out prism (Wiraszka & Gupta, 2012).

1.33 Convergence Excess

Another condition that is produced by an esodeviation is convergence excess. This esodeviation is larger at near than infinity. Convergence excess posture can be simulated by large amounts of uncorrected hyperopia (Brune & Eggenberger, 2018). Approximately six percent of patients can present with this vergence disorder (Cooper, 2020). Negative fusional vergence at near is reduced compared to normal, as base-in prism is not well tolerated by these individuals. As with divergence excess, there is an elevated AC/A ratio. Individuals with convergence excess will not tolerate minus lenses well, as they induce base-in prism. Symptoms of convergence excess include near concerns, such as asthenopia, tiredness, diplopia, etc. Convergence excess is often treated with a plus add or reading glasses for near work (Vivian et al., 2002).

1.34 Convergence Insufficiency

An exodeviation that is larger in magnitude at near than distance is referred to as convergence insufficiency. This condition is common, affecting roughly seven percent of the general population (Cooper, 2020). Positive fusional vergence is reduced in this condition and individuals do not tolerate additional plus lenses. There is a reduced AC/A ratio present, therefore lenses are not an effective treatment for this condition. Symptoms include, but are not limited to, asthenopia, blurred vision, and difficulty concentrating. The most effective treatment of convergence insufficiency is office-based vision therapy with supplemental home therapy (Scheiman et al., 2020).

The Convergence Insufficiency Symptom Survey (CISS) was created to better understand and monitor symptoms of individuals with convergence insufficiency. Table 1 provides the fifteen questions and five answer choices included in the survey. The CISS was found to be an effective way for clinicians to monitor symptoms of individuals affected by convergence insufficiency. An elevated CISS score is not specifically limited to monitoring convergence insufficiency. Since many binocular dysfunctions present with similar symptoms, the CISS can be utilized in such a manner to determine whether other binocular dysfunction disorders are present. Individuals with these dysfunctions present are likely to have an elevated CISS result as compared to binocular vision normal individuals (Pang et al., 2021). Therefore, the CISS can be utilized off-label clinically to monitor symptoms for a variety of binocular vision disorders and is not restricted to convergence insufficiency alone (Marran, et al., 2006).

Table 1 Convergence insufficiency symptom survey

	Never	Infrequently (Not Very Often)	Sometimes	Fairly Often	Always
Do your eyes feel tired when reading or doing close work?					
Do your eyes feel uncomfortable when reading or doing close work?					
Do you have headaches when reading or doing close work?					
Do you feel sleepy when reading or doing close work?					
Do you lose concentration when reading or doing close work?					
Do you have trouble remembering what you have read?					
Do you have double vision when reading or doing close work?					
Do you see the words move, jump, swim, or appear to float on the page when reading or doing close work?					
Do you feel like you read slowly?					
Do your eyes hurt when reading or doing close work?					
Do your eyes ever feel sore when reading or doing close work?					
Do you feel a “pulling” feeling around your eyes when reading or doing close work?					
Do you notice the words blurring or coming in and out of focus when reading or doing close work?					
Do you lose your place while reading or doing close work?					
Do you have to re-read the same line of words when reading?					
Total	*0	*1	*2	*3	*4

1.35 Basic Esodeviation

When the esodeviation found on cover test is relatively equal when viewing targets at both infinity and near, this is considered basic esodeviation. Basic esodeviations are not common and the exact prevalence is unknown (Cooper, 2020). The AC/A is considered normal in these individuals. Negative fusional vergence is reduced at both distance and near. Afflicted individuals will have symptoms of blurred vision and diplopia at distance and/or near. They will have difficulty concentrating and asthenopia. Plus lenses and base-out prism are helpful in treating basic esodeviations (Cooper, 2020).

1.36 Basic Exodeviation

Like basic esodeviations, the magnitude of exodeviation is similar at both distance and near in individuals with basic exodeviation. Basic exodeviations affect almost three percent of the population (Cooper, 2020). AC/A will again be measured as normal in those impacted by this disorder. Reduced positive fusional vergence is present at both distance and near. Symptoms are similar to basic esodeviation, with adverse effects at both distance and near. Office-based vision therapy is the treatment of choice and minus lenses can be utilized as an aide during therapy (Cooper, 2020).

1.4 Accommodation

The ability of the eye to focus near targets when accurately corrected for distance is referred to as accommodation. Uncorrected hyperopes are also required to utilize accommodation to focus a distance target. Accommodative response is controlled by the autonomic nervous system and based on Hering's Law of Equal Innervation; it is believed that innervation for accommodation is bilateral in nature (Ball, 1951). The ciliary body muscles contract, releasing tension on the ciliary zonules. This released tension allows the lens to thicken, creating a more plus-powered lens. The increased plus power allows an individual to view the target clearly.

1.41 Consensual Accommodation

While both eyes are often viewing near targets simultaneously, there are instances where one eye has a view of the target and the other does not. If accommodation was binocular and equal innervation exists between the two eyes, one might assume the accommodative response to be equal between viewing and fellow eyes. It has been found that the consensual response, the accommodative response of the fellow eye, is as strong in magnitude as the eye viewing the target (Chadna et al., 2021). Other research suggests that the consensual accommodative response is decreased compared to the viewing eye, though this is more predominant at more proximal viewing distances and is not necessarily reflected at the typical reading distance of 40cm (Thorn et al., 1984). Equal innervation does not directly correlate to equal accommodative response between the two eyes (Ball, 1952.)

1.42 Accommodative Testing

Amplitudes of accommodation are measured monocularly, most often with the push up method, where a target is brought closer to the viewer until the first sustained blur is noted. This is a direct measurement of accommodation (Cooper, 2020). Based on Hofstetter’s equations, average amplitude of accommodation is considered to be 18 – 0.25*age, while minimum accommodation should be at least 15 – 0.3*age (Castagno, et al., 2017). If an individual does not meet the minimum accommodation for their age, they are more likely to express symptoms and this indicates the presence of accommodative dysfunction.

To assess accuracy of accommodation, monocular estimated method (MEM) is performed clinically. An accommodative target at the site of the retinoscope is provided and the accommodative response is neutralized with lenses (Kothari, et al., 2019). A normal accommodative lag with MEM is considered to be between 0.50D and 1.00D (León, et al, 2017). The presence of MEM value outside of these normative values are indicative of accommodative dysfunction.

To assess flexibility of the accommodative system, accommodative facility is performed, both monocularly and binocularly. Typically, +/-2.00D lens flippers are used. It is expected that individuals should be able to clear both plus lenses and minus lenses at approximately 11 cycles per minute when tested monocularly. Patients with accommodative disorders can have difficulty clearing plus lenses, minus lenses, or both (Cooper, 2020).

1.43 Accommodative Insufficiency

An individual may not be able to accurately accommodate due to a variety of conditions. One such condition is accommodative insufficiency. In this condition, an individual has difficulty stimulating accommodation. There will be an accommodative amplitude that is reduced for one's age (average amplitude of accommodation = 18.5-0.3*age; minimum amplitude of accommodation = 15-0.25*age) (Akujobi, et al., 2018). These individuals may also have difficulty maintaining accurate accommodation or fatiguing with repeated testing. They may present with an excessive lag of accommodation. They may avoid near work and often complain of blurred vision. Added plus lenses for near work and vision therapy are viable treatment options for this condition (Cooper, 2020).

1.44 Accommodative Excess

In contrast, accommodative excess is the condition in which the affected individual is unable to relax their accommodation. This can also be referred to as accommodative spasm. [These individuals may also over-accommodate (have a lead of accommodation), though that is not always the case.] Symptoms may include blurred vision at either distance or near, though it is more often seen after near work. Vision therapy is an effective method in treating accommodative excess (Cooper, 2020). These individuals typically do not like added plus to guide relaxation of accommodation.

1.45 Accommodative Infacility

Individuals that have difficulty adjusting magnitude of accommodative response suffer from a condition known as accommodative infacility. The amplitude of accommodation will be normal, but individuals will find switching accommodative focus to be taxing (Reindel et al., 2018). This is most noticeable clinically when performing accommodative facility testing, where both binocular and monocular facilities are reduced, and individuals have difficulty clearing both plus and minus lenses. These individuals will have difficulty switching focus from distance to near and vice versa. Vision therapy is the best treatment option for individuals that suffer from accommodative infacility (Cooper, 2020).

1.5 Accommodation and Eye Dominance

In a previous study it was found that the dominant eye is likely to accommodate more accurately than the non-dominant eye when viewing binocularly. Lower lags of accommodation were found in the dominant eye. This literature suggests that when both eyes are viewing a target, the dominant eye focuses more accurately. Even so, in monocular conditions there was no significant difference in the accommodative responses between dominant and non-dominant eyes (Fujimura et al., 2017).

1.6 Purpose

A procedure was designed to test accommodation relative to eye dominances, both SED and MED, and how this interaction occurs in individuals with abnormal binocular vision. Eye dominance is not well understood, therefore remains underutilized throughout the optometric community. Through the results of this procedure, better insight as to the effects of eye dominance could be obtained. Consequently, this could lead to better use of eye dominance in aiding individuals with binocular vision dysfunction. One study with two visits was conducted to better understand eye dominance and its effects on accuracy of accommodation.

The purpose of our study is to investigate characteristics of eye dominance as it relates to accommodative functions in a population of young adults with clinical signs and/or symptoms of binocular vision dysfunction, as affected individuals may be symptomatic without clinical evidence. Subjects of this study were young adults up to age 30, with and without previous diagnosis of any binocular vision disorder(s). These individuals were determined to have accommodative/vergence dysfunction based on the

Convergence Insufficiency Symptom Survey and/or clinical testing performed in the first visit. It was preferred that subjects be contact lens wearers (for ease of measurement) or emmetropic, but this was not a requirement. There was no restriction of subjects based on gender.

Chapter 2. Methods

Equipment

During the clinical binocular vision evaluation, a Wesson card, electronic chart, manual phoropter with Risley prism, near point/accommodative ruler, +/-2.00DS flippers, and 12BO/3BI flippers were implemented. For motor eye dominance testing, a grid presented in PowerPoint on a PC at subject's eye level supplied a central target and a round cup with a circular opening was used for sighting the target. Stimuli generated via MATLAB on a PC was presented on a separate monitor and were used to test sensory eye dominance. These stimuli were viewed by subjects through a haploscopic mirror system at a distance of 1 meter. Grand Seiko WAM-5500 Binocular Accommodation Autorefractor/Keratometer (http://grandseiko.com/en/wam-5500-binocular-accommodation-autoref-keratometer) was used to measure both refractive error and dynamic accommodative response accurately. When an eye was to be occluded, the Edmund Optics Optical Cast Infrared (IR) Longpass Filter (https://www.edmundoptics.com/p/4quot-x-5quot-optical-cast-plastic-ir-longpass-filter/5423/) was used to cover the non-viewing eye.

2.1 Characteristics of Subjects

2.11 Acquisition

The methods for this project were approved by The Ohio State University Institutional Review Board. Thirty-six subjects were recruited and screened for binocular vision status from The Ohio State University College of Optometry Classes of 2023-2025. Subjects were recruited based on optometry students being likely to meet eligibility criteria and be available to participate in the project during the period of testing. Subjects were tested over two visit sessions. There were no exclusion criteria for subjects. Visit 1 consisted of baseline testing performed to classify subjects into either the clinically normal binocular vision or abnormal binocular vision classification. Brief familiarization tests were also conducted to prepare the subjects for visit 2. Eighteen abnormal subjects were obtained from this initial screening. Visit 2 tested these subjects' eye dominance and accommodative responses. These are detailed below.

Procedures

2.2 Visit 1

Habitual correction was utilized for all eligibility and experimental testing. While contact lenses and emmetropia were preferred, spectacles were also used by some subjects. Contact lens prescriptions were reported by subjects, while spectacles were measured with a Reichert ML1 manual lensometer. A refraction was performed over habitual correction using a Grand Seiko WAM-5500 autorefractor. Visual acuities were obtained both monocularly and binocularly with a Revised EDTRS chart at 3 meters. Contrast sensitivity was measured both binocularly and monocularly using a Pelli-Robson chart at 1 meter. RANDOT Stereo and Frisby Stereo were performed.

We also familiarized subjects to accommodative and sensory eye dominance testing, which were to be conducted in Visit 2. Monocular accommodation without explicit stimulus was measured by instructing subjects to fixate into the distance. Stimulus was removed by placing an Optical Cast Infrared (IR) Longpass Filter in front of the eye being measured and a black occluder over the companion eye. Consensual accommodation was then measured by supplying a target at 20cm (5D accommodative demand). The IR longpass filter remained over the eye to be measured, while the unmeasured eye was viewing the target.

Similarly, familiarization to sensory eye dominance testing was performed at the first visit. Stimuli were created on MATLAB and presented on a 21-inch monitor. The stimuli were sinusoidal gratings, vertical gratings placed in front of the test eye and horizontal gratings in front of the untested eye, both in front of a gray background. The horizontal gratings maintained stable contrast (1.5 log unit, for most subjects) throughout testing, while the contrast of the vertical gratings varied. Subjects were asked to indicate whether more vertical or horizontal gratings were seen when stimuli were flashed simultaneously. The contrast of the vertical gratings was adjusted until equal predominance was noted. If subjects excessively suppressed an eye during this preliminary testing, the contrast of the untested eye was adjusted accordingly so that this was avoided at the second visit.

2.21 Clinical Binocular Vision Examination

To determine if subjects had abnormal vergence and/or accommodative function, a sensorimotor exam was performed. Normative values used are listed in Table 2. The Convergence Insufficiency Symptom Survey was conducted off-label to gauge symptoms of binocular dysfunction. If subjects reported a score of 21 or higher, they were determined to have binocular dysfunction based on symptoms.

Ocular alignment was assessed with cover test at both distance and near. To perform distance cover test, a 0.3 logMAR letter was presented to the subject. At near, a

20/30 letter was provided as a target. Heterophorias were neutralized until reversal with loose prisms at both distance and near. Von Graefe phorias, in addition to cover test, were assessed behind the phoropter at both distance and near with a vertical 20/30 line of letters for horizontal phoria and a horizontal 20/30 line for vertical phorias. Near fixation disparity was measured with a Wesson Card at 40cm.

Vergence ability was measured both with and without a phoropter. Distance and near smooth ranges with Risley prism were assessed for blur, break, and recovery values. Near point of convergence was assessed using a 20/30 vertical line of letters three times, noting objective eye turn or subjective diplopia. Vergence facilities were conducted, using 12-base-out and 3-base-in prism flippers for one minute. Polarized glasses and polarized line filters were used to monitor for suppression. Subjects were to notify examiner when letters were single and clear and the number of completed cycles per minute were recorded.

Accommodation was also assessed at this visit. Negative and positive relative accommodation, indirect measures of accommodation, were measured within the phoropter with a 20/30 horizontal line of letters. Subjects were to report when the letters became blurred or doubled. Monocular accommodative amplitudes were measured with one eye patched and the tested eye viewing a 20/30 vertical line of letters, asking subjects to report first sustained blur. The right eye's monocular amplitudes were measured three times, looking for signs of fatigue, followed by the left. Monocular accommodative facilities were performed in a similar manner, with the untested eye patched. A 20/30 line of letters was presented to subjects for one-minute intervals, the subject reporting when the letters become clear through the presented plus or minus lens (+/- 2.00D). Binocular accommodative facilities were also performed with polarized glasses and polarized line filters to monitor for suppression. Again, subjects were to report when letters were single and clear and the number of cycles cleared through the plus and minus lenses in one minute were recorded.

Table 2 Clinical binocular vision examination normative values

<table>
<tr><th colspan="5">Clinical Binocular Vision Norms for Adults</th></tr>
<tr><th>Category</th><th colspan="2">Test</th><th>Cut-Off</th><th>Author</th></tr>
<tr><td rowspan="3">Alignment</td><td colspan="2">Distance Cover Test</td><td>4Δ exo – 1Δeso</td><td rowspan="2">Morgan (1944)</td></tr>
<tr><td colspan="2">Near Cover Test</td><td>6Δ exo – ortho</td></tr>
<tr><td colspan="2">Near Fixation Disparity (Wesson Card)</td><td>7.05 arcmin exo, 0.43 arcmin eso</td><td>Dittemore (1993)</td></tr>
<tr><td rowspan="6">Vergence</td><td rowspan="4">Smooth Ranges (Risley Prism) Blur/Break/Recovery</td><td>Distance BI</td><td>X/≥4/≥2</td><td rowspan="4">Morgan (1944)</td></tr>
<tr><td>Distance BO</td><td>≥5/≥11/≥6</td></tr>
<tr><td>Near BI</td><td>≥9/≥17/≥8</td></tr>
<tr><td>Near BO</td><td>≥12/≥15/≥4</td></tr>
<tr><td colspan="2">Near Point of Convergence (Accommodative Target) Break/Recovery</td><td>≤5cm/≤7.5cm</td><td>Scheiman (2003)</td></tr>
<tr><td colspan="2">Vergence Facility (12BO/3BI)</td><td>≥10.4 cpm</td><td>Momeni-Moghaddam (2014)</td></tr>
<tr><td rowspan="5">Accommodation</td><td colspan="2">Monocular Accommodative Amplitudes</td><td>Minimum: 15D-(0.25*age)</td><td>Hofstetter (1944)</td></tr>
<tr><td colspan="2">Monocular Accommodative Facility (+/-2.00DS Flippers)</td><td>≥6 cpm</td><td rowspan="2">Zellers (1984)</td></tr>
<tr><td colspan="2">Binocular Accommodative Facility (+/-2.00DS Flippers)</td><td>≥3 cpm</td></tr>
<tr><td colspan="2" rowspan="2">NRA
PRA</td><td>+1.50D - +2.50D</td><td rowspan="2">(Morgan 1944)</td></tr>
<tr><td>-1.61D - -3.8D</td></tr>
</table>

Δ = Prism Diopter

2.3 Visit 2

2.31 Motor Eye Dominance

To assess motor eye dominance, a laptop with a grid created via PowerPoint was set up eye level with the subject, as displayed in Figure 3. The subject stood one meter from the laptop screen and was given a circular cup with a central aperture. The subject was instructed to stretch arms to full length and sight the center of the grid with the aperture. The subject’s right eye was occluded and the subject was asked to voice what colored number is visible through the aperture. If two numbers were visible to the subject, an average of the two numbers was taken. This same procedure was performed with the left eye covered. Four trials were conducted using a counterbalance method to account for learning curve and fatigue. The counterbalance order for all testing during this visit was as follows: right eye, left eye, left eye, right eye, left eye, right eye, right eye, left eye. Subjects rested their arms between each trial.

Figure 3 MED determination sighting with aperture and monocular occlusion

2.32 Sensory Eye Dominance

Sensory eye dominance was tested in a similar method as listed above. Through the MATLAB code, contrast gratings were presented to both eyes at the same time. If subjects did not suffer from excessive suppression during the initial visit, 1.5 log unit contrast grating was presented in front of the untested eye. If the subject had excessive suppression, contrast grating in the untested eye was adjusted to 1.3 log units. A QUEST method was used to adjust the grating contrast in the tested eye until subjects reported equal vertical and horizontal lines in the field, as reflected in Figure 4. Each eye was tested four times, using a counterbalancing order. Subjects took a break halfway through the four rounds to reduce fatigue.

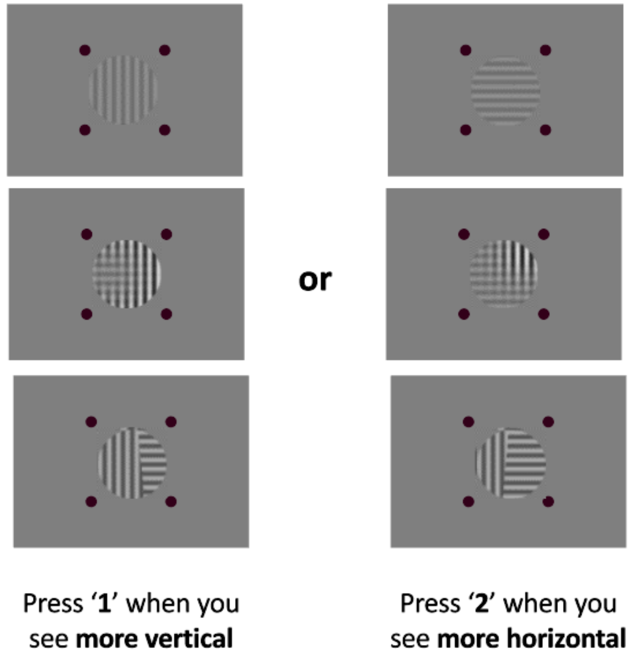

Figure 4 Sensory eye dominance sample images

2.33 Accommodation

Accommodation was measured with the Grand Seiko WAM-5500 autorefractor. Accommodation without explicit stimulus was measured monocularly. An Optical Cast Infrared (IR) Longpass Filter was placed in front of the eye to be measured, while the companion eye was covered with black occluder. This measurement was taken four times for each eye, using a counterbalance method. A break was given halfway through testing to reduce fatigue.

Consensual, direct, and binocular accommodation was tested at a 20cm (5D demand) viewing distance. This accommodative demand was chosen as it most consistently demonstrated lag of accommodation in preliminary testing. If both eyes were viewing the target, though only one eye was measured at a time, it was considered binocular accommodation. Direct accommodation is when the measured eye is also the viewing eye. The unmeasured eye was covered with an infrared filter during this condition. During consensual accommodation, the IR longpass filter was placed in front of the tested eye while the untested eye viewed the target. Four rounds of consensual, direct, and binocular viewing conditions were performed. Breaks were taken by each subject between rounds to prevent fatigue. The order in which the testing was performed was randomized to 18 separate sets (a set for each subject), therefore no subject received the same order of stimuli.

Following near accommodative testing at 20cm, accommodation without explicit stimulation was again tested as described above. This was completed to ensure resting accommodation did not change or fatigue throughout testing. As before, each eye was tested four times with a counterbalancing technique, with a break taken halfway through the four rounds to reduce fatigue.

Chapter 3. Results

3.1 Visit 1: Clinical Binocular Vision Examination

Subjects were deemed to have binocular vision dysfunction based on at least half of binocular vision testing results falling outside of normative values previously listed and/or obtaining a score on the Convergence Insufficiency Symptom Survey (CISS) of ≥21. Table 3 displays both the results from the clinical binocular vision evaluation and CISS scores for subjects with binocular dysfunction. No diagnoses of binocular vision disorders were given following Visit 1. It can be seen that each subject may have been normal in clinical binocular vision testing but are deemed symptomatic with the CISS. Subjects may also be asymptomatic but fall outside the normal limits for the majority of tests. Table 4 demonstrates the percentage of subjects that fell inside and outside of normal limits for each test. Near cover test revealed abnormal results in the most subjects, with 88.89% falling outside of normal range. In contrast, distance base-in smooth vergence ranges revealed the least subjects with abnormal results, with only 5.56% subjects revealing abnormal values.

Subjects that had binocular vision dysfunction had an average age of 23.9 years. Seventy-six-point five percent of these subjects were female, while only twenty-three-point five percent were male. Ninety-four-point one percent of subjects were right-handed, while five-point nine percent of subjects were left-handed. The average binocular visual acuity was -0.16 logMAR, with an average acuity of the right eye of -0.10 logMAR and of the left eye -0.10 logMAR. Binocular contrast sensitivity presented with an average 1.91 log unit. The contrast sensitivities of right and left eyes were each 1.76 log unit. The average CISS score was 19.53. The mean values of each test within the clinical binocular vision examination are listed in Table 5.

Table 3 Results from visit 1 testing for subjects with abnormal binocular vision

Subject	Number of Tests Within Normal Values	Number of Tests Outside of Normal Values	CISS score
4032	5	11	4
4029	9	7	22
4046	4	12	19
4035	10	6	21
4024*	6	9	21
1109	7	9	8
1113	7	9	16
1104	10	6	25
1108	9	7	19
1110	11	5	33
1107*	7	9	18
1117	11	5	24
1120	10	6	22
1121	11	5	30
1122	8	8	27
1124	9	7	28
1125	9	7	10
1123	8	8	3

*subject excluded from Visit 2 data due to extreme binocular vision dysfunction and/or inability to complete testing

Table 4 Percent of normal/abnormal test results based on clinical test

n = 18	**Test**	**% Subjects Normal**	**% Subjects Abnormal**
	Distance Cover Test	50.00%	50.00%
	Near Cover Test	11.11%	88.89%
	Near Fixation Disparity	22.22%	77.78%
	Distance Base-In Ranges	94.44%	5.56%
	Distance Base-Out Ranges	77.78%	22.22%
	Near Base-In Ranges	27.78%	72.22%
	Near Base-Out Ranges	61.11%	38.89%
	Near Point of Convergence	55.56%	44.44%
	Vergence Facilities	44.44%	55.56%
	Monocular Amplitude of Accommodation	47.22%	52.78%
	Monocular Accommodative Facility	86.11%	13.89%
	Binocular Accommodative Facility	55.56%	44.44%
	Negative Relative Accommodation	44.44%	55.56%
	Positive Relative Accommodation	33.33%	66.67%

Table 5 Mean Values of the Binocular Vision Examination

Test	Average
Distance Cover Test	3.56Δ exodeviation
Near Cover Test	1.47Δ exodeviation
Distance von Graefe Phoria	0.36Δ base-down, 0.29Δ base-in
Near von Graefe Phoria	0.03Δ base-down, 0.88Δ base-in
Near Fixation Disparity	5.22 minutes of arc exo
Distance Base-In Ranges	no blur, break 8.83Δ, recovery 5.39Δ
Distance Base-Out Ranges	blur 11.75Δ, break 20.17Δ, recovery 15.22Δ
Near Base-In Ranges	blur 13.90Δ, break 13.90 Δ, recovery 7.94Δ
Near Base-Out Ranges	blur 12.00Δ, break 22.50Δ, recovery 13.86Δ
Near Point of Convergence	break at 5.80cm, recovery 6.19cm
Vergence Facilities	8.86 cpm
Monocular Amplitude of Accommodation	10.87D right eye, 11.04D left eye
Monocular Accommodative Facility	11.92 cpm right eye, 12.25 cpm left eye
Binocular Accommodative Facility	6.14 cpm
Negative Relative Accommodation	+2.50D
Positive Relative Accommodation	-2.67D

Δ: prism diopter; cpm: cycles per minute

3.2 Visit 2: Eye Dominance and Lag of Accommodation

From Visit 1, sixteen subjects were deemed to have binocular vision dysfunction. One subject was unable to complete Visit 2 due to extreme abnormal values and symptoms throughout the clinical binocular vision examination. Another subject completed both visits, but her data is excluded from Visit 2 results. This is due to extreme fluctuations in responses throughout both binocular vision evaluation and accommodative testing that resulted in their data being outliers.

During Visit 2, subjects' sensory eye dominance (SED) and motor eye dominance (MED) were determined. We were able to quantify the strength of SED using the log contrast of the gratings that balanced the 1.5 (or 1.3) log contrast gratings in the untested eye. However, it is not possible to quantify MED. While we attempted to utilize a grid to determine magnitude of MED, the true magnitude is dependent on the length of the subject's arms and the proximity of the aperture to the sighting target. Therefore, MED was determined to be the sighting eye, without a quantifiable strength.

Accommodative responses were obtained from each subject using data recorded by the WAM-5500 autorefractor. The response of accommodation was determined by comparing the responses to the demand for accommodation (5D). These accommodative responses were adjusted based on each subject's over-refraction; thus, the lag of accommodation was recorded in lieu of collected accommodative responses.

3.21 Sensory Eye Dominance

Determined sensory eye dominances were then compared to the lag of accommodation of each subject. Figure 5 and Table 6 display the SED, both dominant and non-dominant eyes, and the average lag of accommodation in binocular, direct, and consensual test conditions. Table 7 exhibits no significant difference in lag of accommodation was found between dominant and non-dominant eyes [$F(1.00, 15.00) = 0.003$, $p = 0.960$, 2-way ANOVA with repeated measures]. This is found to be true at all test conditions [$F(1.22, = 0.680$, $p = 0.448$, 2-way ANOVA with repeated measures]. There was a significant difference in lag of accommodation between test conditions [$F(1.32, 19.83) = 5.022$, $p = 0.028$, 2-way ANOVA with repeated measures]. Table 8 shows that in post-HOC testing, it was found that lag of accommodation is significantly different between binocular and consensual test conditions [$t(31) = -2.620$, $p = 0.020$, pairwise paired T-Test], as well as direct and consensual conditions [$t(31) = -2.675$, $p = 0.020$, pairwise paired T-Test]. Generally, this data shows that an eye accommodates less accurately when not directly viewing a target with no effect of SED.

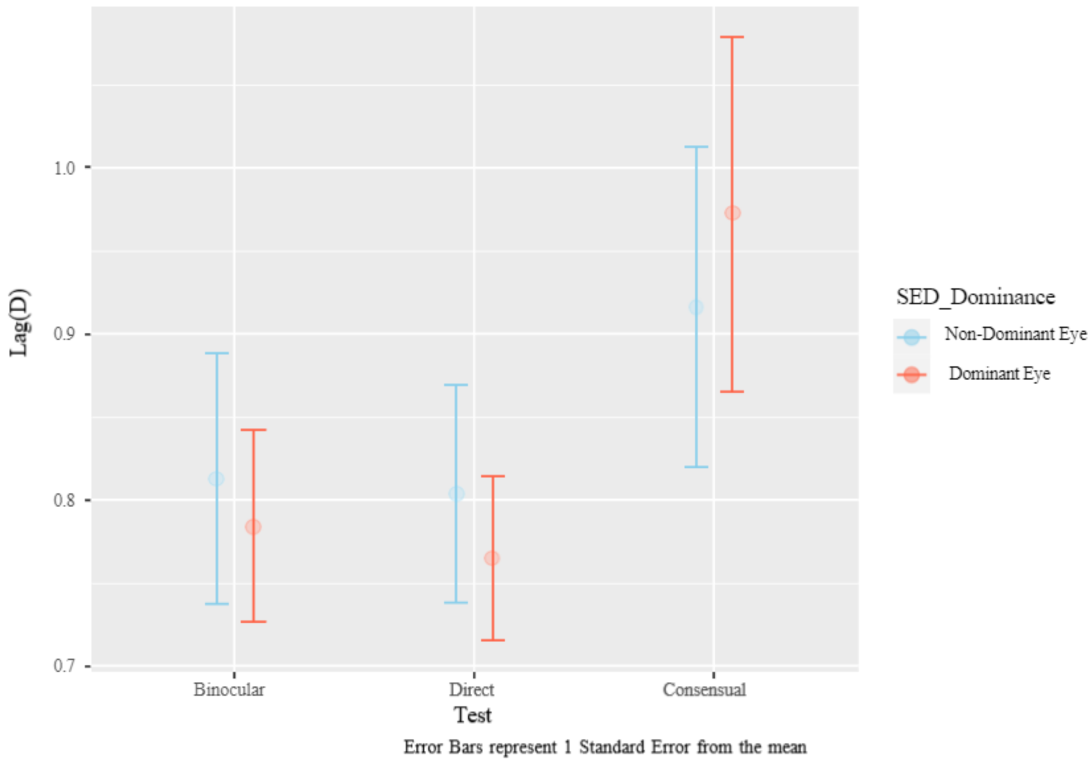

Figure 5 Lag of accommodation based on sensory eye dominance and test condition

Table 6 Lag of accommodation based on sensory eye dominance and test condition

Test	SED_Dominance	se	Lag(D)	y-min	y-max
Binocular	NonDom	0.0752976	0.8123329	0.7370353	0.8876304
Binocular	Dom	0.0578507	0.7842369	0.7263862	0.8420876
Direct	NonDom	0.0656148	0.8039369	0.7383222	0.8695517
Direct	Dom	0.0497813	0.7645033	0.7147220	0.8142845
Consensual	NonDom	0.0964512	0.9162459	0.8197948	1.0126971
Consensual	Dom	0.1067448	0.9724407	0.8656959	1.0791855

NonDom: Non-dominant eye, Dom: dominant eye, se: standard error, lag: lag of accommodation

Table 7 SED and lag of accommodation repeated measures ANOVA

Effect	DFn	DFd	F	p	Generalized Eta-Sq
Test	1.32	19.83	5.022	0.028*	5.40e-02
SED_Dominance	1.00	15.00	0.003	0.960	3.91e-05
Test: SED_Dominance	1.22	18.25	0.680	0.448	5.00e-03

*: significant; DFn: numerator of F ratio, Dfd: denominator of F ratio; Generalized Eta-Sq: Generalized Eta-Squared

Table 8 SED, test condition, and lag of accommodation pairwise paired t-test

Category	group1	group2	n1	n2	statistic	df	p	p.adj	p.adj.signif
Abnormal	Binocular	Direct	32	32	0.468876	31	0.642	0.642	ns
Abnormal	Binocular	Consensual	32	32	-2.620196	31	0.014	0.020	*
Abnormal	Direct	Consensual	32	32	-2.674821	31	0.012	0.020	*

*: significant; ns: not significant; df: degrees of freedom; p.adj: adjusted p-value; p.adj.signif: significance of adjusted p-value

3.22 Motor Eye Dominance

In similar fashion, MED was compared to the determined lags of accommodation. Figure 6 and Table 9 display average lag of accommodation for both MED dominant and MED non-dominant eyes at all test conditions. In similar fashion to the results concerning SED, Table 10 shows there is no significant difference in lag of accommodation between dominant and non-dominant eyes [$F(1.00, 15.00) = 1.429$, $p = 0.251$, 2-way ANOVA with repeated measures], which remains true in all test conditions [$F(1.20, 18.03) = 0.145$, $p = 0.754$, 2-way ANOVA with repeated measures]. Even so, a significant difference in lag of accommodation between test conditions was revealed [F(1.32, 19.83)

= 5.022, p = 0.028, 2-way ANOVA with repeated measures]. For post-HOC testing, Table 11 shows that there is a significant difference in accuracy of accommodation between binocular and consensual conditions [t(31) = -2.620, p = 0.020, pairwise paired T-Test] and direct and consensual conditions [t(31) = -2.675, p = 0.020, pairwise paired T-Test]. These results display that lag of accommodation is not affected by eye dominance, rather by whether the eye is viewing the accommodative target.

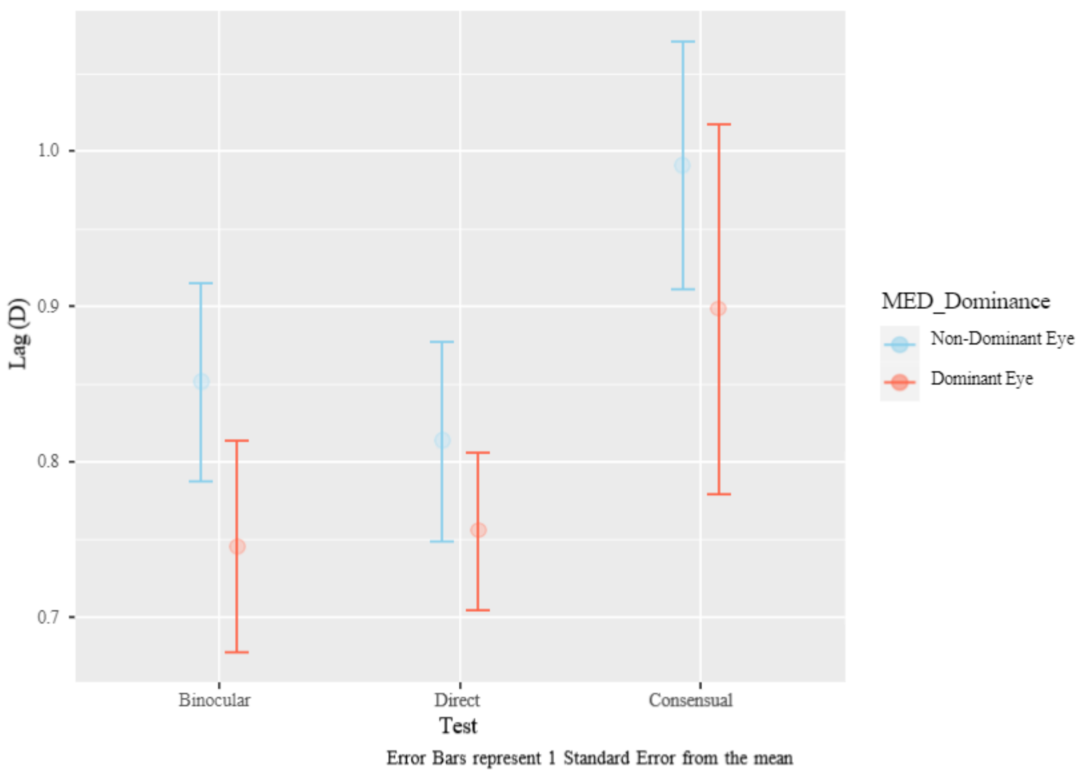

Figure 6 Lag of accommodation based on motor eye dominance and test condition

Table 9 Lag of accommodation based on motor eye dominance and test condition

Test	MED_Dominance	se	Lag(D)	y-min	y-max
Binocular	NonDom	0.0636561	0.8508554	0.7871993	0.9145116
Binocular	Dom	0.0679864	0.7457143	0.6777279	0.8137007
Direct	NonDom	0.0643277	0.8130679	0.7487402	0.8773956
Direct	Dom	0.0508556	0.7553723	0.7045166	0.8062279
Consensual	NonDom	0.0799002	0.9905964	0.9106962	1.0704965
Consensual	Dom	0.1188834	0.8980903	0.7792069	1.0169736

NonDom: Non-dominant eye, Dom: dominant eye, se: standard error, lag: lag of accommodation

Table 10 MED and lag of accommodation repeated measures ANOVA

Effect	DFn	DFd	F	p	Generalized Eta-Sq
Test	1.32	19.83	5.022	0.028*	0.055
MED_Dominance	1.00	15.00	1.429	0.251	0.020
Test: MED_Dominance	1.20	18.03	0.145	0.754	0.001

*: significant; DFn: numerator of F ratio, Dfd: denominator of F ratio; Generalized Eta-Sq: Generalized Eta-Squared

Table 11 MED, test condition, and lag of accommodation pairwise paired t-test

Category	group1	group2	n1	n2	statistic	df	p	p.adj	p.adj.signif
Abnormal	Binocular	Direct	32	32	0.468876	31	0.642	0.642	ns
Abnormal	Binocular	Consensual	32	32	-2.620196	31	0.014	0.020	*
Abnormal	Direct	Consensual	32	32	-2.674821	31	0.012	0.020	*

*: significant; ns: not significant; df: degrees of freedom; p.adj: adjusted p-value; p.adj.signif: significance of adjusted p-value

Chapter 4. Discussion

4.1 Summary of Findings

This research assessed the accuracy of accommodative responses in young adults with binocular vision dysfunction in relationship with eye dominance. Our goal was to determine whether the dominant eye, either MED or SED, accommodated more accurately than the non-dominant eye. These results could influence how the condition of eye dominance is integrated into clinical care, especially with the fitting and prescribing of monovision and multifocal contact lenses or with bioptic telescope fittings.

This study found that there is no significant difference between the accuracy of accommodation between dominant and non-dominant eyes under all test conditions. Whether accommodation was tested under binocular, direct, or consensual test conditions, the dominant eye and non-dominant eye presented with similar accuracy of accommodation. While there was no difference in accommodative accuracy between eyes, accommodative accuracy between consensual, binocular, and direct testing conditions. Consensual testing demonstrated the most accommodative lag.

Our finding of no significant difference between the accommodative responses of the dominant and non-dominant eyes was somewhat unexpected. This is because accommodative ability can be asymmetric between the two eyes and, consequently, can impair an individual's ability to focus on a near target (Marran & Schor, 2000). When presented with dichoptic stimuli of two different magnitudes, an aniso-accommodative response could be elicited. This furthers the idea that the eye has some independent control of accommodation (Marran & Schor, 2000). Unequal accommodation is most obviously seen in individuals with anisometropic amblyopia. The amblyopic eye will present with less accurate accommodation compared to the normal eye. In some cases, the amblyopic eye may accommodate opposite to expectation, eliciting a larger accommodative response at distance than near (Toor & Riddell, 2018). The aniso-accommodation exhibited by affected individuals could indicate that accommodation is not always equal and entirely binocular (yoked) in nature. Furthermore, a previous study by Fujimura, et al. (2017) found that the dominant eye is more likely to have accurate accommodation under binocular conditions, with the non-dominant eye having a lag of 0.25D larger than the dominant eye. This is likely not clinically relevant. In contrast, there was no significant difference found between accommodative accuracy in monocular conditions, with the non-dominant eye having less than a 0.10D increase in lag.

May and Gamlin (2020) investigated whether accommodation is bilateral or unilateral in macaque monkeys. A rabies virus was injected into the ciliary muscle tagged with fluorescent markers. Brainstems were extracted and viewed under a microscope, assessed for the presence of markers. The authors found that some neurons were labelled with markers from both eyes, while others were labelled with only markers from the ipsilateral or contralateral eyes. This further supports the idea that the accommodative pathway can be controlled both binocularly and monocularly. Perhaps this anatomical study might provide a possible explanation for our finding of a larger lag in consensual accommodation.

Furthermore, consensual accommodation has been found to be less accurate than direct accommodation in human studies. In one study, the accommodative difference between consensual and direct viewing eyes was approximately 0.15D (Thorn, et al., 1984). The non-seeing eye has been found to accommodate 70-80% as strong as the eye directly viewing the target. This difference becomes more obvious as the accommodative demand increases (Ball, 1951). This data provides insight into the accommodative pathway and that direct viewing of a target creates more accurate accommodation, as in our findings.

4.2 Limitations

The criterion for this study specifically investigated individuals with accommodative/vergence dysfunction. If a strabismus or phoria is present, it is likely that the subject's eyes became misaligned while covered. This leads to the possibility that the autorefractor measurements were not taken directly through the center of the visual axis. One would expect the accommodative response to be significantly reduced if measured outside of the visual axis. Heilman, et al. (2018) discovered that if the accommodation of a lens was measured ten degrees off the visual axis, approximately 7D increase in lag of accommodation was revealed. The defocus of a peripheral lens would increase in an accommodative state. The magnitude of the deviation in degrees can be converted into prism diopters, utilized in our study, with a trigonometric equation: degrees = $\tan^{-1}$(prism diopter/100) x (180/π), so a ten degree deviation would be equivalent to approximately a

20 prism diopter deviation on cover test (Irsch, 2015). Many subjects produced a deviation on cover test that was roughly half of that (~10D). Some may assume that if the deviation is cut in half, approximately 3.5D increase in lag of accommodation would be expected. Even so, when we measured consensual accommodation, a maximum of less than 0.25D mean increase in average lag of accommodation was found between binocular and consensual test conditions. Therefore, we can assume the measurements of accommodation through the autorefractor were taken through, or in close proximity to, the visual axis throughout accommodative testing.

This study was limited by the number of subjects classified as having binocular vision dysfunction. With a sample size of only 16, the lack of substantial data affects the ability to reach concrete evidence-based conclusions.

Future directions with this research could include revisiting accommodative accuracy in individuals with binocular vision dysfunction with monovision correction. Both the conventional method of fitting the dominant eye for distance and non-dominant eye for near, and vice versa, could be utilized to determine which fitting style provides most accurate accommodation in early presbyopes who still retain some accommodative ability.

4.3 Conclusion

Our study protocol allows us to perform more thorough testing of accommodation and determine if eye dominance influences the accuracy of accommodation. Presently, it does not appear that eye dominancy provides a significant impact on accuracy of accommodation for individuals with binocular vision dysfunction. It would be interesting to compare the accommodative findings of our sample, those with binocular vision disorders, to age-matched normal (individuals who do not have binocular vision dysfunction) under the same testing conditions. Further testing in this sample and a larger sample size would contribute to more concrete insight as to whether eye dominance has a true effect and how practitioners can utilize eye dominance clinically, specifically for improving patient satisfaction with clinical implications, such as monovision and multifocal contact lens fittings, bioptic telescope fittings, and sports vision training.

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