Eye Dominance Preference for Near Task of Young Adults with Clinically Normal Binocular Vision

Thesis

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Abstract

Eye dominance refers to the preference to use one eye rather than the other to perform a visual task. Like many of the other laterally paired structures in humans, one eye is often more dominant than the other. With the eyes, this dominance is often further broken down into both sensory eye dominance (SED) and motor eye dominance (MED). Sensory eye dominance is described as one eye being more visually sensitive than the other[3], while motor eye dominance refers to the preference to use one eye over the other to sight an object while viewing binocularly.

In this study, we examined the relationship between both SED and MED and accommodative response under various test conditions in individuals with clinically normal binocular vision. This allowed us to determine if the accommodative response differs between the two eyes based on eye dominance.

This study consisted of two visits with the first visit being used to classify participants as having either clinically normal or abnormal binocular vision. This determination was made based on the sensorimotor exam results and subjective symptoms using the Convergence Insufficiency Symptom Survey (CISS), which were collected during the first visit. Twenty-one participants were classified as having clinically normal binocular vision and returned for a second study visit. At the second visit, SED was measured using a binocular rivalry technique and MED was measured by

having subjects binocularly sight a target and alternatively covering each eye to determine which eye more accurately sighted the target. Next, the binocular, direct, and consensual accommodative responses of both the dominant and non-dominant eyes were dynamically measured using the WAM 5500 autorefractor while viewing a target at 20cm (5D accommodative demand).

Analysis of the data found no significant difference in the accommodative response under any test condition based on either sensory [$F(1.1, 20.95)=0.371$, $p=0.569$] or motor [$F(1.1, 20.97)=0.031$, p=0,883] eye dominance. However, there was an unexpected significant difference in accommodative response between test conditions [$F(2.0, 38.0)= 14.968$, $p=0.00002$]. Specifically, the amount of accommodative lag was significantly higher in the consensual test condition than under both the binocular [$t(39)=-3.042$, $p=0.006$] and direct [$t(39)=-3.563$, $p=0.003$] test conditions. This was surprising given the prevailing knowledge that accommodation is yoked between the two eyes.

Acknowledgments

First, I would like to thank my advisor, Dr. Ooi for her help and guidance through this whole process. This entire project, from the early days of planning to analyzing the data and writing this thesis, would not have been possible without her. I would also like to thank both Dr. Mutti and Dr. Walline for giving their time and effort to serve on my thesis committee. Next, I would like to thank my classmate and lab partner Emily Weatherford for her help seeing study participants. I would not have been able to complete all the study visits without her help. Lastly, I would like to thank my family for all their support and reassurance throughout this entire process.

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Introduction

The preference to use one eye rather than the other to perform a visual task is known as eye dominance. The phenomenon of dominance is not unique to the eye and is seen in many bilaterally paired structures in the body, such as the arms and legs.[1] In humans, eye dominance can be broken down further into sensory and motor dominance components. Interestingly, there may be one eye that is both the sensory and motor dominant eye, or there may be one eye that is the sensory dominant eye, while the other is the motor dominant eye.[6, 13] For example, it is possible for the right eye to be the motor dominant eye while the left eye is the more sensory dominant eye. To understand the relevance of eye dominance, it is important to first learn what sensory and motor eye dominance are and how they are measured. This will be discussed in the following paragraphs.

Motor eye dominance is also often referred to as sighting dominance. The motor dominant eye is the eye that is preferred to sight an object while viewing binocularly. The most common method for determining motor eye dominance is the "sighting test." In this test a subject binocularly sights a target through a hole, or simply points at a target, and then closes each eye in turn.[6] The eye that is more accurately sighting the target while the other remains closed is said to be the motor dominant eye.[6, 3] In another version of this test, a subject binocularly sights an object through a hole and then slowly brings the hole straight back along the line of sight. The eye that the hole ends up in front of is the motor dominant eye.[2] The possible clinical significance of motor eye dominance will be discussed later.

Sensory eye dominance is described as one eye being more visually sensitive than the other.[3] This is most often measured by taking advantage of either the binocular rivalry or the binocular phase combination phenomena.[6] In a binocular rivalry test, visually rivalrous stimuli are presented to each eye. The stimuli, typically orthogonal sine wave gratings, are briefly presented dichoptically and the participant reports which stimulus orientation is perceived to make up more of the flashed stimulus.[6] Based on the response of the participant, the luminance or contrast of the stimulus for the eye being tested is varied until the frequency of each image being perceived is equal.[6, 3] The test is then repeated for the opposite eye. In this technique, the luminance or contrast level required for the gratings to be perceived as equal is referred to as the balance point and provides a quantitative measure of sensory eye dominance.[6] This measure is often referred to as the interocular imbalance.[6, 3] Individuals that have a very sensory dominant eye will require a larger difference in luminance or contrast between the stimuli for them to be perceived equally, with the less dominant eye requiring a stimulus of higher luminance or contrast than the dominant eye.

As mentioned above, sensory eye dominance may also be measured using binocular phase combination stimuli.[6, 4] This method also utilizes dichoptic images, however, in this test the images contain features that are similar enough to be integrated into a single image.[4] A study by Han et. al. (2018) compared the sensory eye dominance testing results between the binocular rivalry and binocular phase combination stimuli test methods. This study found each method measured sensory eye dominance with similar results in both identifying the dominant eye and measuring the amount of dominance present.[4] This indicates that both testing strategies are acceptable methods for measuring sensory dominance.

Although the concept of eye dominance is well accepted and well known, the actual mechanism behind the phenomenon of eye dominance remains unclear. Some researchers theorize that one eye may perform sensory and/or motor tasks more efficiently, which leads to the more efficient eye being preferred for certain types of tasks.[6] Additionally, sensory eye dominance has garnered more research interest than motor eye dominance, leading to a paucity in the number of studies on motor eye dominance.[6] Because of this, the relationship between sensory and motor eye dominance continues to be poorly understood, particularly as to why the sensory and motor dominances can occur in opposite eyes. Along with this, there is poor correlation between measures of sensory and motor dominance.[2] Moreover, a study by Aswathappa et al. (2011) found that there is also no significant correlation between the laterality of hand and eye dominance in humans.[1] Therefore, evidence for possible mechanisms contributing to eye dominance will be discussed in the following paragraphs.

Eye dominance has been shown to be a binocular phenomenon and does not appear to be caused by one eye necessarily having a weaker monocular signal, or there being an obvious difference in the cortical processing of the signals between the eyes.[6,2] This implies that there is some sort of interaction that occurs between the eyes when they are working together that gives rise to eye dominance.[2] The idea that eye dominance is sensory in nature is supported by the fact that eye dominance has been demonstrated to be more strongly correlated with stereopsis threshold measurements than with monocular measurements, such as contrast sensitivity or visual acuity.[6, 4] It is not believed that the retina of the more dominant eye is better at sensing light than the non-dominant eye, but rather that the differences are cortical in nature. This leads to the hypothesis that there is an imbalance of interocular inhibition and/or integration between the eyes, which contributes to sensory eye dominance.[4] For example, the dominant eye may be better at suppressing visual input from the fellow eye when an interocular imbalance or inhibition exists, which ultimately makes it the dominant eye.

Additionally, further support of a cortical mechanism of eye dominance comes from amblyopia, a neurodevelopmental disorder associated with very strong sensory eye dominance.[6, 3] This suggests that a neural mechanism is contributing to the development and maintenance of eye dominance, particularly in regard to sensory dominance, although, it is unknown if the neural changes are the same as those present in amblyopia.[6, 3] Moreover, the primary visual cortex in the occipital lobe is the first place input from each eye is combined to give functional binocular vision, indicating that visual input and processing at the level of the primary visual cortex may be very important in determining eye dominance.[3] Ooi et al. (2020) hypothesized that because most functions of binocular vision are computed in an ordered fashion, there are likely many neural loci that play into eye dominance, rather than there being a single dominance locus.[6] There is evidence to support this theory as neural activity has been measured in the extrastriate cortices, striate cortices, and the lateral geniculate nucleus related to binocular rivalry.[6]

Now that we have discussed possible contributors to mechanisms behind eye dominance, we will consider some of the possible real-world applications to address when it comes to eye dominance. Clinically, eye dominance is important to take into consideration when an optometrist or ophthalmologist is deciding which eye to use for distance, and which eye to use for near when prescribing monovision refractive correction.[7] Most commonly, the sensory dominant eye is the eye that is prescribed the distance correction in monovision patients.[7] Another clinically relevant application of eye dominance is its effect on stereopsis threshold; it has been found that individuals with greater sensory eye dominance tend to have higher stereopsis threshold measures.[6, 4]

There are also significant implications for eye dominance outside of eyecare, particularly when it comes to athletics. Studies have shown that the relationship between the laterality of hand and eye dominance can affect the performance of athletes in some sports.[5] In a study by Laborde and Dosseville (2009) the authors reported that, "considering sports like shooting, interaction between hand preference and eye dominance seems a relevant factor in performance."[5] This study found that in shooting sports, athletes possessing uncrossed eye-hand dominance patterns (where the dominant eye and hand occur ipsilaterally) are more successful than those with crossed eye-hand dominance (where the dominant eye and hand occur on contralateral sides).[5] Specifically, they observed that archers with uncrossed eye-hand dominances tended to score significantly higher than those archers with crossed eye hand dominance. Baseball is another example of a sport where performance may be affected by eye-hand dominance. A study by Adams (1965) reported that batting in baseball may be impacted in some part by the laterality of the batter's hand-eye dominance; those with uncrossed dominances performed significantly better in many batting statistical categories than those with crossed dominances.[7]

As stated earlier, it is known that pathology, such as amblyopia, can cause an increase in sensory eye dominance. It is also important to consider eye dominance in individuals with clinically normal binocular vision. Li et al. (2010) performed measures of eye dominance in individuals considered to have normal binocular vision.[2] In this population, they found there was not a normal distribution of the amount of eye dominance measured.[2] Rather, they found two clusters of participants; one large cluster had weak eye dominance and one small cluster had a stronger measured eye dominance.[2] Along with this, they found that those with stronger eye dominance performed more consistently on tests of both sensory and motor dominance.[2] This makes sense as you would expect individuals possessing stronger dominance to rely on their dominant eye more than those with very little dominance. This also demonstrates that some individuals with clinically normal binocular vision may still have a strong eye dominance.[2] This finding confirms the earlier finding by Ooi and He (2020).

Accommodation refers to the change in shape of the crystalline lens occurring while viewing near objects. During accommodation the ciliary muscle of the eye contracts which results in decreased tension of lens zonules and thickening of the crystalline lens.

This thickening leads to an increase in the dioptric power of the lens, allowing for the clear viewing of near objects.

Although accommodation allows the eye to focus on near objects, in most cases the actual accommodative response is less than the dioptric demand calculated based on the viewing distance. The difference between the accommodative demand and the actual accommodative response is known as accommodative lag. A small amount of accommodative lag is considered normal, however excessive amounts are considered abnormal. Typically, an accommodative lag of between +0.50D to +0.75D is considered to be the normal range. Although having an accommodative lag is considered normal, having an accommodative lead is not. In an accommodative lead the amount of accommodation is greater than the actual accommodative demand.

The level of accommodative response is affected by many different factors. One significant factor that affects the amount of accommodative response is target distance. As demonstrated by McClelland and Saunders (2004), when target distance decreases and the accommodative demand increases, the amount of accommodative lag tends to increase as the system becomes more strained from the higher demand.[18] Another factor that impacts the accommodative response is uncorrected refractive error. In both emmetropic individuals and those with proper refractive error correction the accommodative demand is equal to that calculated based on target distance. However, in those with uncorrected myopia the actual accommodative demand is less than the calculated demand, and therefore the accommodative response will be less than expected. The opposite holds true for those with uncorrected hyperopic refractive errors. The accommodative demand for these individuals is actually greater than that calculated based on target distance, and therefore their actual accommodative response will also have to be greater to clearly see the target.

Another significant factor affecting the accommodative response is eye alignment. Individuals with an exophoric posture at near viewing distance often tend to overaccommodate to a near target in order to drive accommodative convergence and keep the target single. This overaccommodation causes there to be very low amounts of accommodative lag, and sometimes even an accommodative lead where the accommodative response is greater than the accommodative demand for the target. On the other hand, those with an esophoric posture at near may sometimes underaccommodate to a target to prevent stimulation of accommodative convergence as this extra convergence would lead to an increase in esophoric posture. This underaccommodation leads to a higher than normal amount of accommodative lag in these individuals.

The most accepted theory of accommodation is that the accommodative response is yoked, and therefore the level of accommodation is equal between the two eyes.[16] Typically, it is believed that if the accommodative demand is unequal between the two eyes, such as in uncorrected anisometropic hyperopia, the accommodative response in each will be equal to that needed to achieve a clear image in the eye with the lesser accommodative demand.[16] If this theory holds true, then the accommodative responses measured should be equal between the two eyes under each testing condition in this study. The testing conditions will allow isolation and measurement of the direct, binocular, and consensual accommodative responses of each eye. By isolating the accommodative responses separately, we will be able to further break down the relationship between eye dominance and accommodation to determine if the different interactions are found under the various testing conditions.

Although this study is looking at the relationship between eye dominance and accommodative response under various conditions in those with clinically normal binocular vision, the results could be applicable to a broader population. By better understanding how the accommodative response varies under different conditions in the normal population, we may be able to better understand where the underlying problem is in those with abnormal binocular vision, particularly in those where accommodative dysfunction plays a large role in their binocular vision problems. Better understanding where the underlying problem is in these individuals could lead to improved and more targeted treatment of their binocular vision dysfunction.

The purpose of this study is to investigate eye dominance and accommodative response in young adults with clinically normal binocular vision. Several different measurements of binocular vision will be used to determine if a subject qualifies as having clinically normal binocular vision. Then both sensory and motor eye dominance will be measured, along with the accommodative response under various conditions. These data will then be analyzed to investigate the relationship between eye dominance and the accommodative response.

Equipment

The WAM-5500 Binocular Accommodation Autorefractor/keratometer (http://grandseiko.com/en/wam-5500-binocular-accommodation-autoref-keratometer) has has been shown to be accurate and reliable as both an autorefractor and for dynamically measuring accommodative response.[9] To measure the accommodative response of an occluded eye, an infrared (IR)-pass filter (Edmund Optics 43954 Filter Optcast IR 4' x 5') was used. The IR-pass filter occludes the eye while still allowing the WAM-5500 to measure the accommodative response. Prior to being used in the study, the filter was tested using a model eye provided by the instrument. The measurements were found to be accurate, indicating this as an effective way to measure the accommodative response of an occluded eye.

Methods

This study design included completion of two separate study visits. The study enrolled young adults under thirty with and without self-reported eye or visual conditions. The age cutoff was established to prevent the normal age related decline in accommodation from affecting results. There was no gender restriction as there are no known differences in eye dominance or accommodation based on gender. Thirty-nine participants completed the first study visit. The purpose of the first visit was to quantify study participants as having either clinically abnormal or clinically normal binocular vision based on symptoms and sensorimotor exam findings. Of the participants completing the first visit, twenty-one were found to have clinically normal binocular vision and qualified to complete the second study visit. Of these twenty-one who qualified, twenty returned and completed the second study visit.

The first study visit began by obtaining written consent to participant to take part in the study. All risks and benefits of taking part in the study were discussed with each participant, and written consent was obtained before beginning the first study visit. Various tests were then performed to establish the participants’ baseline visual status.

Binocular dysfunction symptom survey

First, the convergence insufficiency symptom survey (CISS) was administered to each participant in order to gauge if the participant may have symptoms of binocular dysfunction.

Visual acuity and contrast sensitivity

After completing the CISS, the clinical testing portion of the study began. Distance visual acuity was measured both binocularly and monocularly using the ETDRS chart at 3 meters. 160cd/m^2 illumination was used and the participant was instructed to read the first letter of each line starting at the top of the chart and working their way down until a letter was missed. The participant was then redirected three lines above the missed letter and instructed to move down the chart reading each chart letter by letter until missing more than half the letters on a line. Once the end point, which is the point when the subject stopped reading, was reached, the acuity was scored using letter by letter scoring and recorded in logarithmic notation. Following VA measurements, both unilateral and alternating cover test were performed at distance and near (40cm) to detect and measure the presence of strabismus or heterophoria. If present, the magnitude of strabismus or phoria was recorded in prism diopters. Next, both binocular and monocular contrast sensitivity were measured using the Pelli-Robson chart at 1 meter with 80cd/m^2 illumination.

Stereoacuity and fixation disparity

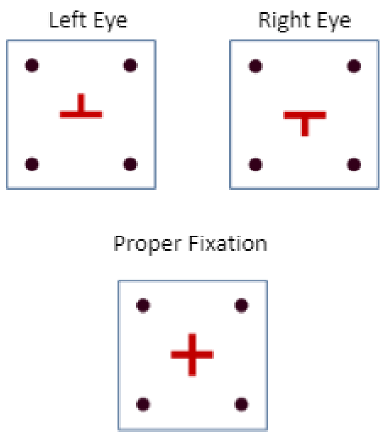
Randot stereoacuity was performed at the standard test distance of 40cm. First, R+L suppression check was performed to ensure the patient was binocular. During this phase the participant was asked if the R and L were equally visible or if one was darker or bolder to provide some possible insight into eye dominance. Next, both global and local stereo were performed. Following randot stereoacuity testing, fixation disparity was assessed using the Wesson card at 40cm. Stereoacuity was then reassessed using the Frisby Stereo Test. This allowed threshold stereoacuity to be measured using octaves.

Accommodation

A WAM 5500 autorefractor was used to obtain baseline measurement data and familiarize the participant with the testing. An over-refraction was measured 3 times for each eye while the participant viewed a 20/32 letter at distance binocularly through their habitual correction. Accommodative response without explicit stimulation was measured while both eyes were occluded to get an idea of the level of resting accommodation and to detect any differences in adaptation of accommodation before beginning testing. To obtain this measurement, the study participant was asked to continue to focus at distance as both eyes were covered, and the accommodative response was measured through the IR-pass filter occluding the eye being measured. This measurement was taken for each eye. The last measurement taken with the WAM 5500 during the first visit was the consensual accommodative response while viewing a 0.8m target at 20cm (5D accommodative demand). For this measurement, one eye was occluded with the IR filter while the other viewed the near target. The dynamic accommodative response was measured at a frequency of 6 hertz over 5 seconds.

Sensory eye dominance

Next, a practice sensory eye dominance (SED) testing was completed to allow the participant to become familiar with how the testing works. SED was measured using the binocular rivalry technique of Han et al.[4] In this technique the eye being tested views a vertical sine wave grating with a set contrast while the fellow eye views a horizontal sine wave grating. The contrast of the sine grating viewed by eye being tested was varied from 0.376-1.976 log unit based on participant's response, while the horizontal grating viewed by the fellow eye was held constant at 1.5 log units. Before testing, the participant was aligned in the testing set-up and instructed to view a fixation cross made from nonius lines (Fig 1A below). Once the participant had proper fixation, they pressed the control button of the keyboard to begin the testing. This removed the nonius target and then 146ms later sine grating targets were briefly presented on the screen for 400ms. After the sine grating presentation, a mask of random black and white dots was presented. The participant then indicated which grating orientation, either horizontal or vertical, they perceived more using the keyboard (fig 1B below). The contrast of the vertical grating was adjusted and the stimulus presented again, with the goal being to find the contrast required for equal perception of the two gratings. Equal perception was assumed when the horizontal and vertical gratings were perceived with equal frequency. This process was repeated for a total of 40 trials per testing block. One block for each eye was performed during the first visit.



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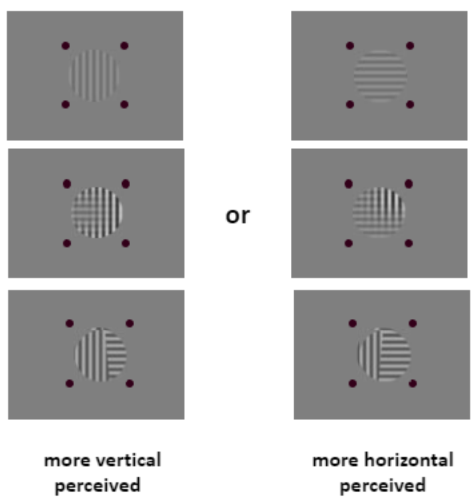

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Figure 1: Figure 1A demonstrates the nonius line target used for SED testing; Figure 1B demonstrates possible perceptions of the sine gratings during SED testing.

Binocular vision

The remainder of the first visit consisted of binocular vision testing and was completed in a clinical exam lane. The first several tests were conducted through a manual phoropter. The phoropter was set to plano if the participant was wearing contact lenses, or to the habitual spectacle prescription if they were wearing glasses. All distance testing was conducted before near testing to help prevent overstimulation of accommodation at near that could affect distance testing results. To start, the Von Graefe method was used to obtain a subjective measure of both the horizontal and vertical heterophoria at distance. For this testing, along with all other distance testing, the patient viewed a single 20/32 letter H with crowding bars. The dissociating prism (6 BU for horizontal, 12 BI for vertical) was placed over the left eye and the measuring prism was placed over the right eye for each measurement. Along with this, the flashing technique was utilized to help prevent the participant from fusing the images. Next, horizontal Risley prism vergence ranges were measured at distance with base in being performed before base out. Subjective blur, break, and recovery values were recorded for each.

After distance testing was performed, both Von Graefe phoria measurements and Risley prism ranges were measured at near. All near testing was conducted with the participant viewing 1mm letters that subtended 8.5’ at 40 cm. The last testing conducted through the phoropter was negative relative accommodation (NRA) and positive relative accommodation (PRA). For NRA plus lenses were added binocularly in 0.25D steps until subjective blur was reported. Similarly, for PRA minus lenses were added in 0.25D steps until subjective blur was reported.

The remainder of the testing was completed outside of the phoropter. Near point of convergence (NPC) was measured by having the subject view a vertical column of letters on a measuring rod. The letters were moved in toward the patient until they reported subjective doubling of the target, then moved back until the subject reported the column was single again. This process was then repeated for a total of 3 measurements. Both break and recovery values were recorded to the nearest half centimeter. Next, monocular accommodative amplitude was measured using the push-up method. For this test, one eye was patched while the other viewed the column of letters. The letters were moved in toward the participant until they reported sustained blur. The blur value was recorded to the nearest half centimeter and then later converted to diopters. This test was performed 3 times per eye.

Monocular accommodative facility was the next procedure performed. For this testing, one eye was patched as the fellow eye was tested. +/- 2.00D lens flippers were used as the participant focused on a target at 40cm. Testing for each eye was performed for one minute and the results recorded as cycles per minute.

Binocular accommodative facility was performed the same way as the monocular facilities, except the patient was binocular and a polarized filter was used to ensure the subject was not suppressing an eye. Testing was performed for one minute and the results recorded as cycles per minute.

Lastly, vergence facility was performed binocularly using 3BI/12BO prism flippers as the patient viewed a target at 40cm with a polarized filter. Testing was performed for one minute and the results recorded as cycles per minute.

Both clinical measurements and participant reported symptoms were compared to 16 different normative values to classify the participant as having clinically normal versus clinically abnormal binocular vision. The ranges of normative values used in this study were developed by Dr. Maureen Plaumann as part of her PhD candidacy exam and are listed in Table 1. If a participant had more values that fell within the normative ranges than outside the ranges, they were classified as having clinically normal binocular vision. If more than half of a participant's values fell outside the normative ranges, then they were classified as having clinically abnormal binocular vision. However, if the participant had an equal number of values that fell both inside and outside of the normative ranges then participant-reported symptoms from the CISS survey were taken into consideration in the classification. Table 2 below gives a breakdown of CISS score and how many values were within the normative range for each participant that was classified as having clinically normal binocular vision. Table 3 provides the same information for those classified as having clinically abnormal vision after the first study visit. Those classified as having clinically normal binocular vision were then asked to return and complete a second study visit.

Category	Test		Cut-off		Within Range	Outside of Range
Alignment	Distance Cover Test		[4Δ exo, 1Δ eso]		1	
	Near Cover Test		[6Δ exo, Ortho]		1	
	Near Fixation Disparity (Wesson Card)		[7.05 arcmin exo, 0.43 arcmin eso]		1	
Vergence					**Satisfies Conditions**	**Doesn't Satisfy Conditions**
	Smooth Ranges (with Risley prism) Blur/Break/ Recovery	Distance BI	X / ≥4Δ /≥2Δ		1	
		Distance BO	≥5Δ / ≥11Δ /≥6Δ		1	
		Near BI	≥9Δ /≥17Δ/ ≥8Δ		1	
		Near BO	≥12Δ/ ≥15Δ/ ≥4Δ		1	
	Near Point of Convergence (break/recovery) Accommodative target		≤5/≤7.5		1	
	Vergence Facility (12BO/3BI)		≥10.4 cpm		1	
Accommodation	Monocular Accommodative Amplitudes		Average: 18.5 – (0.3*age) Minimum: 15 – (0.25*age)		**< Minimum**	**> Minimum**
			Age	Minimum (cm)		
			18	9.5		
			19	9.8		
			20	10		
			21	10.3		
			22	10.5		
			23	10.8		
			24	11.1		
			25	11.4	2	
			26	11.8		
			27	12.1		
			28	12.5		
			29	12.9		
			30	13.3		
					Satisfies Conditions	**Doesn't Satisfy Conditions**
	Monocular Accommodative Facilities		≥6 cpm		2	
	Binocular Accommodative Facility With +/- 2.00D flippers		≥3 cpm		1	
	NRA		[+1.50, + 2.50]		1	
	PRA		[-1.61, -3.85]		1	
	Total				Normal	BV Dysfunction
					16	0

Table 1: List of binocular vision normative values used to determine binocular vision status (developed by Dr. Maureen Plaumann). The data for study participant 4033 is used to demonstrate how binocular vision was determined.

Visit 2:

The second study visit primarily consisted of testing to measure motor eye dominance, sensory eye dominance, and accommodative response under various test conditions.

Motor eye dominance

Motor eye dominance (MED) was measured using a grid on a computer. The grid had a central dot target surrounded by rows and columns of colored numbers. This grid was positioned 1 meter from the participant at eye level. The participant then held a circle at arm's length and binocularly sighted the central target on the grid. The examiner would then alternately cover each eye and record the number and color the participant reported seeing on the screen through the hole. This process was then repeated a total of 4 times The eye that more accurately fixated the central target was considered to be the motor dominant eye.

Sensory eye dominance

Next, sensory eye dominance was measured. Each eye was tested in a counterbalanced fashion using the same procedure previously described and used during the first visit. Testing was performed 4 times for each eye, for a total of 8 trials. The eye that needed the lower contrast to achieve equal perception was determined to be the sensory dominant eye.

Accommodative response

Accommodative response was then measured with the WAM 5500 autorefractor under various conditions. The first condition was the consensual response under occlusion. As in the first visit, the participant focused on a distance target while both eyes were occluded. One eye was occluded using an IR-pass filter to allow the accommodative response to be measured, then the occluders were switched and the opposite eye was measured. This sequence was completed 4 times, with a short break given in the middle. Each measurement was recorded dynamically over a 5 second period. The average accommodative measurements for each eye were then calculated.

The next set of testing measured the accommodative response at near using a target at 20 cm, i.e., a 5-diopter accommodative demand. This testing occurred in blocks, with each block consisting of direct, consensual, and binocular accommodative response measurements for each eye. For the direct accommodative response, one eye was covered while the other viewed the target, and the accommodative response of the viewing eye was measured. Then the opposite eye was occluded as the fellow eye viewed the target. For the consensual response one eye viewed the near target while the other was occluded using the IR-pass filter. The filter allowed the consensual accommodative response of the occluded eye to be measured. Once the first eye was measured, the filter was switched, and the consensual response of the fellow eye was measured. Lastly, the accommodative response of each eye was measured while the participant viewed the target binocularly. Figures 2 and 3 below demonstrate the set-up used to acquire the accommodative measurements under each test condition. These measurement blocks were repeated 3 more times, with a short break between each block to help reduce the impact of participant boredom and fatigue on the measurements. As before, each measurement was dynamically recorded over a period of 5 seconds. It is also important to note that the testing sequence for each block was randomized to help counteract the impact of measurement sequence on measurement outcomes.

Once the last testing block above was completed, the resting accommodation response without explicit stimulation was measured again using the same technique previously described. These measurements were than compared to the resting accommodative measures taken earlier in the study to ensure that the near testing did not induce accommodative spasm.

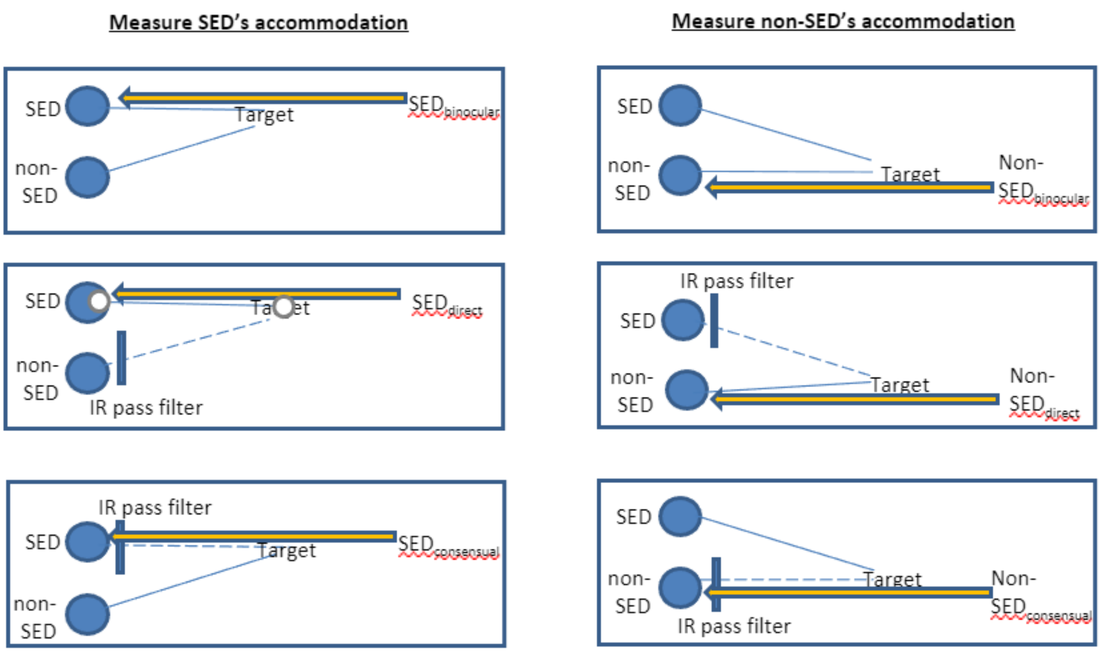

Figure 2: Demonstrates the set-up for the accommodative measurements in regards to SED under each test condition

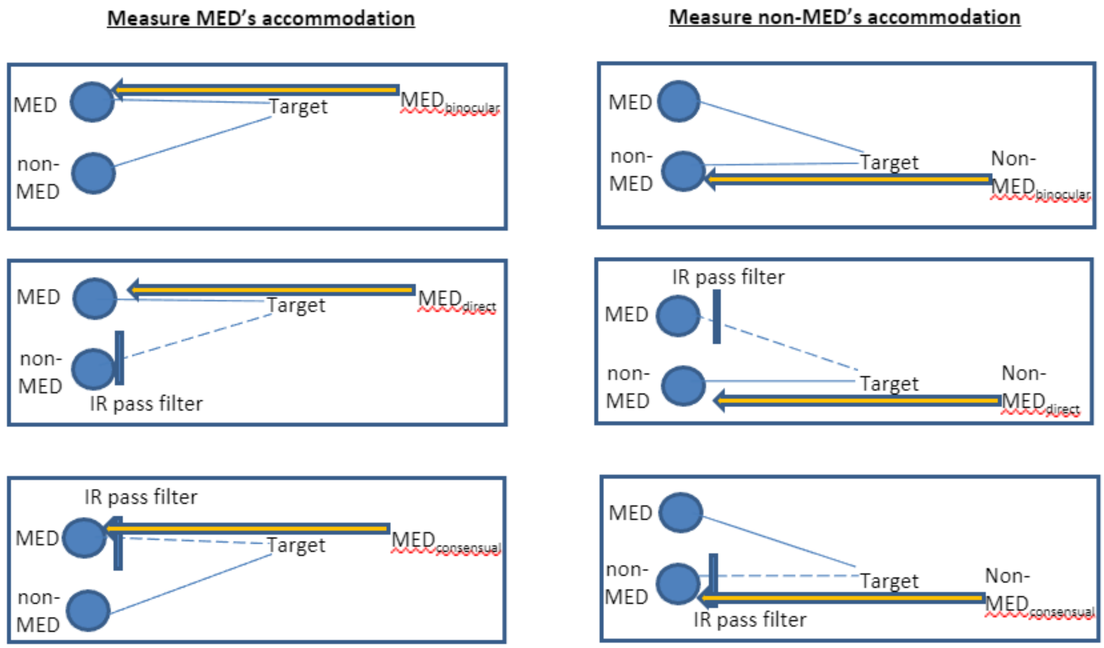

Figure 3: Demonstrates the set-up for the accommodative measurements in regards to MED under each test condition

Results

In total, 21 subjects were classified as having clinically normal binocular vision. Of those, 20 returned to complete the second study visit. Of the 20 subjects that completed both study visits, the CISS scores ranged from 2 to 18, with an average of 9.35 (*sd*=4.41). As expected, this is much lower than 21, which is the score commonly used as the threshold for having clinically significant symptoms. As demonstrated in table 2 below, testing also showed that only 6 of the 20 participants had crossed eye dominance where one eye was the sensory dominant eye and the fellow eye was the motor dominant eye. This suggests that in the clinically normal binocular vision population ipsilateral dominance is more common than contralateral dominance.

	BV findings						
Participant	**Normal**	**Abnormal**	**CISS**	**Hand Dom**	**MED**	**SED**	
4033	16	0	8	right	RE	RE	
4034	10	6	11	right	RE	RE	
4039	12	4	15	right	RE	LE	opposite
4040	14	2	5	right	RE	RE	
4043	11	5	14	right	RE	RE	
4047	14	2	5	right	RE	LE	opposite
4057	12	4	5	right	RE	RE	
4031	12	4	3	right	RE	LE	opposite
1106	13	3	12	right	LE	LE	
1111	15	1	5	right	RE	RE	
1112	10	6	18	right	RE	RE	
1114	15	1	11	right	RE	RE	
1115	13	3	9	left	LE	LE	
4053	10	6	2	right	LE	RE	opposite
4051	11	5	11	right	LE	LE	
1118	13	3	11	right	RE	RE	
4049	14	2	4	right	RE	LE	opposite
1119	12	4	15	right	LE	RE	opposite
1116	12	4	11	right	LE	LE	
4052	12	4	12	right	RE	RE	

Table 2: Binocular vision profile, hand dominance, and laterality of eye dominance for participants classified as having normal binocular vision

Abnormal Group BV findings			
Participant	Normal	Abnormal	CISS
4032	5	11	4
4029	9	7	22
4046	4	12	19
4035	11	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	11	5	22
1121	10	6	30
1122	8	8	27
1123	8	8	3
1124	9	7	28
1125	9	7	10

Table 3: Binocular vision profile and CISS score of those classified as having abnormal binocular vision. No SED/MED relationship is listed for these participants as they did not complete the second visit of the study where this data was obtained.

Although the WAM-5500 autorefractor measures the actual accommodative response of the eye, we used the amount of accommodative lag present in our data analysis. The accommodative lag was used because, although the target was placed at a 5D demand, the actual demand varied for each participant depending on any residual refractive error. To account for this, the over refraction measured by the WAM-5500 was taken into consideration to determine that actual accommodative demand individually for each participant and each eye. The measured accommodative response was then subtracted from the calculated demand to calculate the accommodative lag present. For example, if a participant had an over-refraction of -0.25D, this would decrease the actual accommodative demand and result in a calculated accommodative demand of 4.75D. The measured accommodative response would then be subtracted from this new demand with the difference in the measures being the accommodative lag. It is also important to note that of the twenty participants completing both study visits that four were wearing no refractive error correction, fourteen were wearing soft contact lenses, and two were wearing glasses during testing. This is important because both over-refraction and accommodative measurements were adjusted for effectivity in the two participants wearing glasses during the study.

The first interaction analyzed was that between SED and amount of accommodative lag under each test condition. Figure 4 below plots the average amount off accommodative lag present under each test condition for both the sensory dominant and non-dominant eyes. Analysis of this relationship via 2-way Repeated Measures ANOVA revealed that the amount of accommodative lag, regardless of test condition, was not found to be significantly different between the two eyes regardless of which was the sensory dominant eye [$F(1.1, 20.95)=0.371$, $p=0.569$]. However, a significant interaction between amount of accommodative lag and test condition [$F(2.0, 38.0)=14.968$, $p=0.00002$] was found to exist. Post-hoc testing of this relationship via paired t-test between test conditions found the amount of accommodative lag under the binocular test condition is significantly less than under the consensual test condition [$t(39)=-3.042$, $p=0.006$]. Post-hoc testing found that the amount of lag present under the direct test condition was also significantly lower than that present under the consensual test condition [$t(39)=-3.563$, $p=0.003$]. Lastly, the testing found no significant difference between the amount of accommodative lag present under the binocular and direct test conditions [*t*(39)=1.423, *p*=0.163].

Next, linear regression analysis was performed to compare the relationship between accommodative lag and accommodative demand in SED vs non-SED eyes., which is plotted in Figure 5 below. Analysis found no significant interaction in the accommodative lag-demand relationship between SED and non-SED groups under the binocular [F(1, 36) = 0.48, p = 0.49], direct [F (1, 36) = 1.82, p = 0.19], or consensual [F(1, 36) = 0.27, p = 0.61] test conditions.

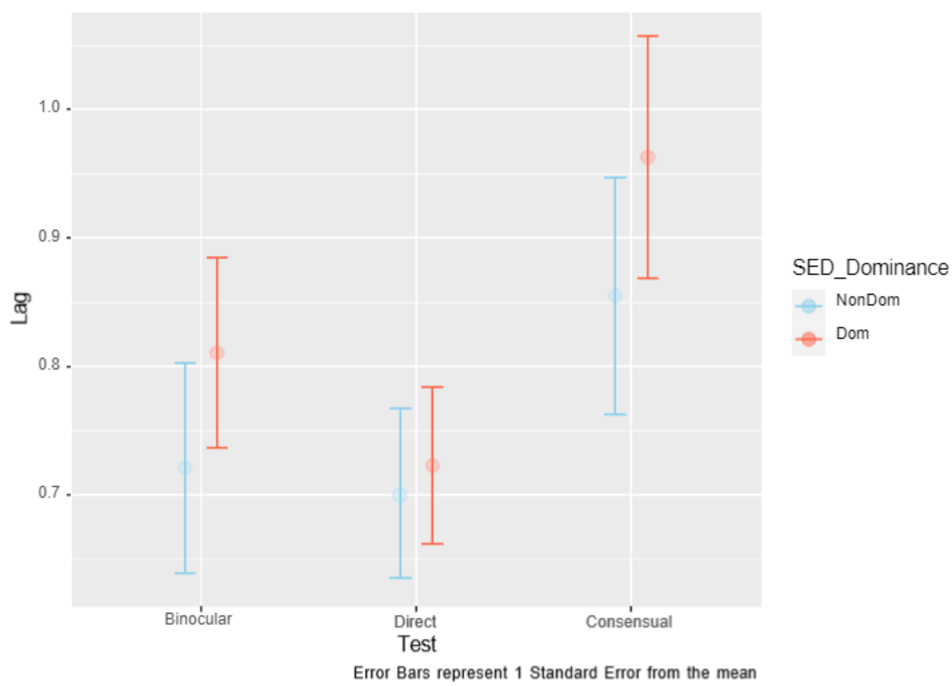

Figure 4: Plot of the average accommodative lag present under each test condition for SED and non-SED eye

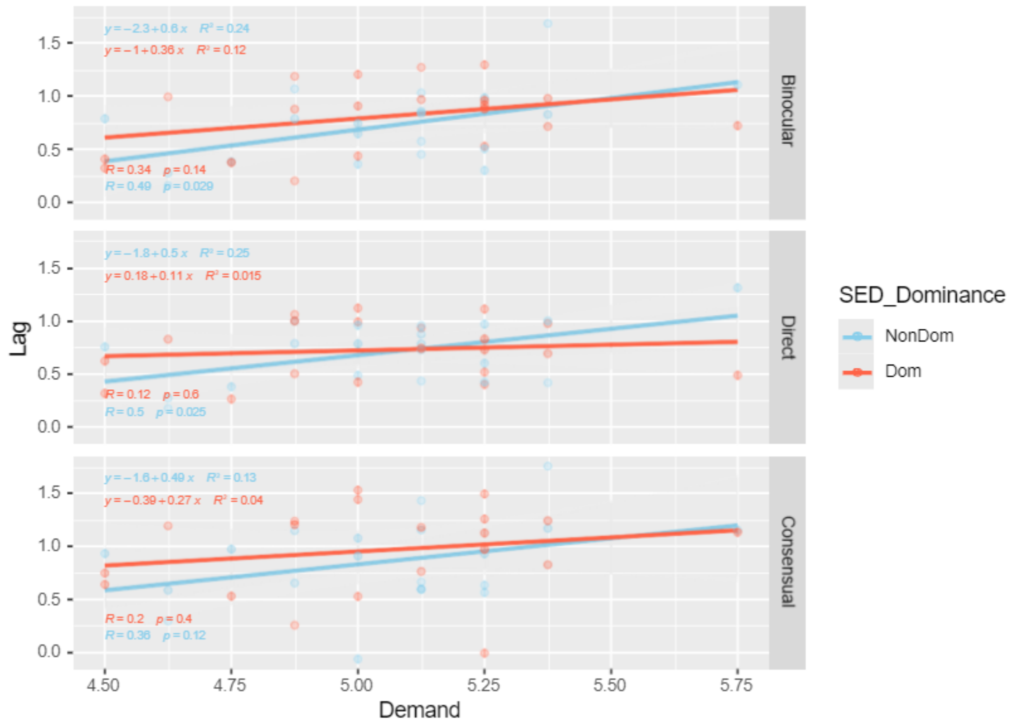

Figure 5: Plot of the amount of accommodative lag in the SED and non-SED eyes under each test condition. It also shows that under each test condition both SED and non-SED eyes show increased amount of lag with increased accommodative demand.

Next, the interaction between MED and amount of accommodative lag under each test condition was analyzed. Figure 6 below plots the amount of accommodative lag present under each test condition separately for both the motor dominant eye and non-dominant eye to demonstrate these relationships. Analysis of this relationship via 2-way Repeated Measures ANOVA revealed that the amount of accommodative lag, regardless of test condition, was not found to be significantly different between the two eyes regardless of which was the motor dominant eye [$F(1.1, 20.97)=0.031$, $p=0.883$]. Similar as with SED, we found a difference in amount of accommodative lag present based on test condition [*F*=2.0, 38.0) =14.968, *p*=0.00002]. More specifically, post-hoc analysis via paired t-test between test conditions revealed that the amount of accommodative lag was significantly lower under binocular test condition than under consensual test condition [$t(39)=-3.042$, $p=0.006$). Similarly, the amount of lag under the direct test condition was also found to be significantly less than that under the consensual condition [$t(39)=-3.563$, $p=0.003$]. However, the amount of accommodative lag between the binocular and direct test conditions was not found to be significant [$t(39)=1.423$, $p=0.163$].

Next, linear regression analysis was performed to compare the relationship between accommodative lag and accommodative demand in MED and non-MED eyes. This analysis found no significant interaction in the lag-demand relationship between MED and non-MED groups under the binocular [$F(1, 36) = 0.72$, $p = 0.40$], direct [$F(1, 36) = 0.04$, $p = 0.85$], or consensual [$F (1, 36) = 0.20$, $p = 0.65$] test conditions. This relationship is plotted in Figure 7 below.

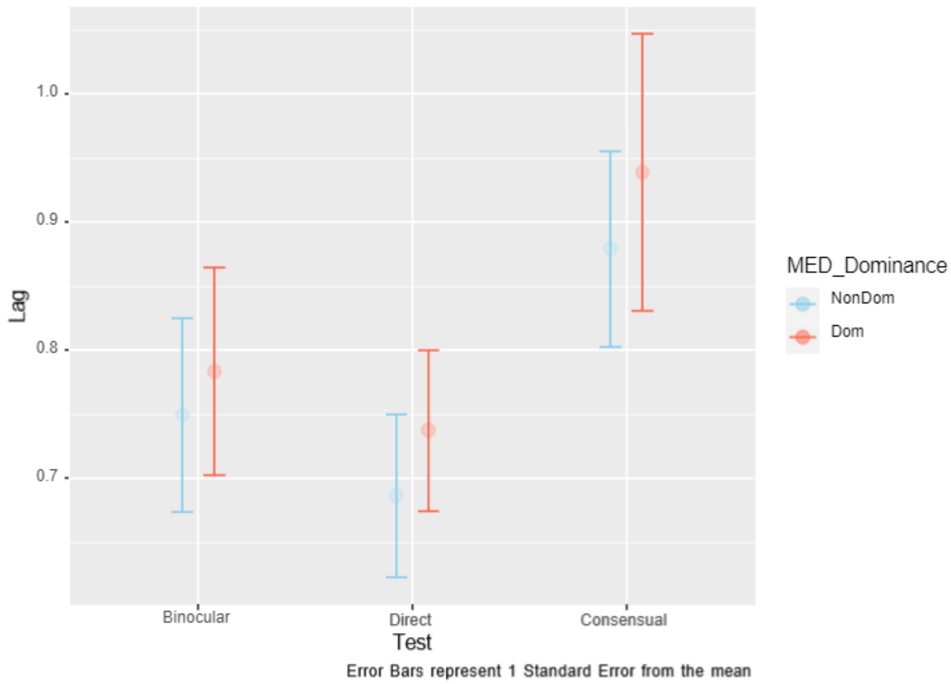

Figure 6: Plot of average accommodative lag present under each test condition for MED and non-MED eye

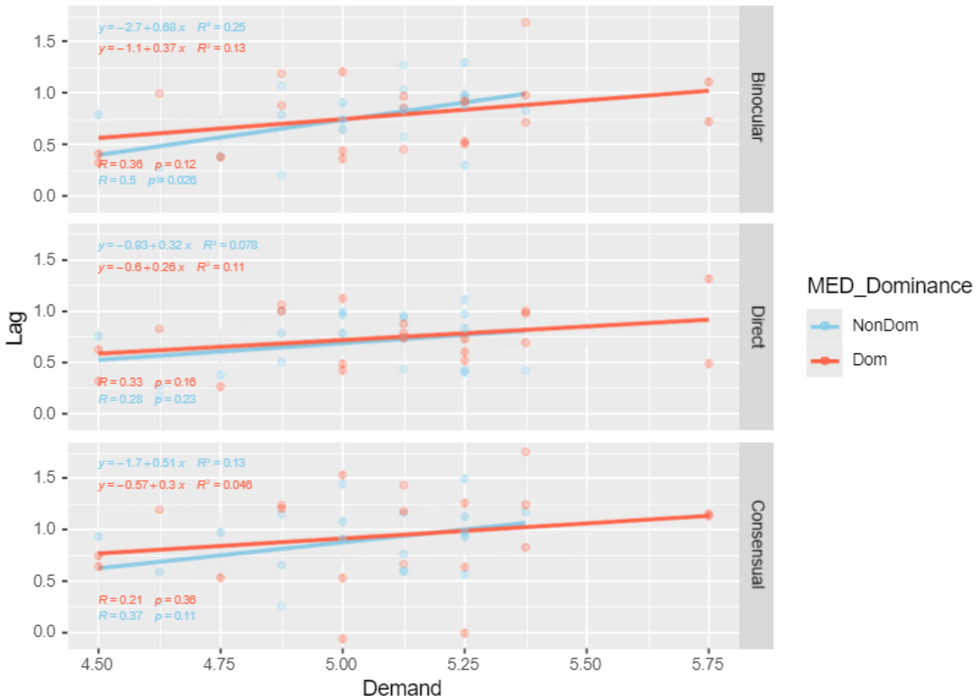

Figure 5: Plot of the amount of accommodative lag in the MED and non-MED eyes under each test condition. It also shows that under each test condition both MED and non-MED eyes show increased amount of lag with increased accommodative demand.

Discussion

The finding that the consensual accommodative response was significantly different from the response under binocular and direct conditions challenges the typical assumption that the accommodative response between the two eye is 100% yoked and should therefore be equal between the eyes. Although the direct and consensual responses are typically thought of as being equal, a study by Thorne et al found that the direct and consensual responses often differ by significant amounts.[11] This finding supports our finding that the consensual accommodative lag was significantly greater than that of the direct response.

May and Gamlin investigated the laterality of innervation to the ciliary body driving accommodation in Macaca fasicularis monkeys. They found both bilateral and unilateral premotor neurons, indicating that accommodation is both binocularly and monocularly controlled.[12] They hypothesize that the bilaterally projecting neurons allow a yoked accommodative response between the two eyes, and that the unilaterally projecting neurons allow for limited adjustment of accommodation in one eye.[12] This supports the idea that the level of accommodation is not always equal between the two eyes.

Although the previously mentioned studies provide support for our results, a study by Chandna et al. directly contradicts our findings. Their study found that the accommodative response of each eye was equal under direct and consensual conditions.[10] It is worth noting that the accommodative demand in the above study never exceeded 3D, whereas the accommodative measurements in our study were performed with 5D demand. This is important because accommodative response and lag tends to be more variable at higher demands. Therefore, it is possible that the differences in the direct and consensual responses found in this study are more pronounced under higher accommodative demands. Another difference between our study and that of Chandna et al's is that their study measured the accommodative response using the PlusOptix Power Refractor III. This device measures the accommodative response using eccentric photorefraction; a different method than the WAM-5500 autorefractor used in our study.[15] The PlusOptix Power Refractor III also allows for simultaneous measurement of the accommodative response of each eye, whereas the WAM-5500 can only measure one eye at a time. Simultaneous measurement is likely a better method of measurement as it limits the affect of variability of both participant attentiveness and accommodative response between trials.

Tarutta and Tarasova measured the direct and consensual accommodative response using an open-field autorefractor and keratometer. Interestingly, they found no significant difference between the direct and consensual response when measuring hyperopic, emmetropic, and low/moderate myopic individuals, but they did find a significant difference in those individuals with high and anisometropic myopia.[13] They believe that this information could be used clinically to identify those most at risk for becoming highly myopic.[13] Identifying these at-risk individuals could allow earlier initiation of myopia control treatment, thus potentially limiting the amount of myopia developed. It is worth noting that three of the participants in our study would be considered to be high myopes (using a cutoff of -6.00 D), and two different participants were anisometropic myopes (using cutoff of 1.50 D difference between the eyes). In our limited sample size, there does not appear to be a strong relationship showing that these individuals had higher differences in lag between direct and consensual test conditions.

The fact that there was no interaction between eye dominance and accommodative lag was unexpected. We hypothesized that the more dominant eye, particularly regarding motor eye dominance would have a more accurate accommodative response, and therefore have lower amounts of accommodative lag than the non-dominant eye. Specifically, we thought that the motor dominant eye would have lower amounts of accommodative lag due to the motor component of ciliary body contraction in the act of accommodation. We thought that just as one eye is favored when sighting an object in regard to MED, that one eye may be favored in regards to accommodative response.

We believe that the lack of significance of the interaction between accommodative response and eye dominance may largely be due to the limited sample size in this study. For example, if you visually analyze the SED data in figure 4 it appears that there could potentially be a difference in the amount of accommodative lag between the SED and non-SED eyes that is most noticeable under the binocular and consensual test conditions. Surprisingly, this difference seems to be the opposite of what we had hypothesized. As discussed previously, we thought that the dominant eyes would have lower amounts of accommodative lag, but it appears that the non-dominant eyes may actually tend to have the lower amount of lag. When thinking about SED we predicted that the dominant eye would be more sensitive to blur and therefore would likely accommodate more accurately in order to have a clearer image. Data analysis finds that the difference is not significant, however any differences would likely become more apparent had there been more participants in the study. Unlike with SED, visual analysis of the data for accommodative lag in the MED versus non-MED eyes in Figure 6 does not appear to show a strong trend. This makes sense, because as mentioned previously, data analysis found no significant interactions with this data.The difference in trends in SED compared MED data may indicate that SED is more likely to have an impact on the accommodative response than MED.

Although we were surprised that there was no significant interaction between eye dominance and accommodative response, these results are consistent with those found in a previous study comparing eye dominance by Momeni-Moghaddam et al. In this study motor eye dominance as determined by the hole in card method and the amount of accommodative lag was measured using the monocular estimation method (MEM) and compared between the dominant and non-dominant eyes. As with our study, they found that there was no significant difference in the amount of accommodative lag between the dominant and non-dominant eyes.[17] Unlike our study, they also compared both accommodative amplitude and monocular accommodative facility between the dominant and non-dominant eyes. They found that the dominant eye has statistically significant greater accommodative amplitude and facility.[17]

Limitations

There are several limitations with this study. One such limitation is that the WAM-5500 only allows measurement of one eye at a time. It would have been preferable to be able to measure the two eyes simultaneously to control for the stability of participants' attention level, as they might have slightly different attention level between trials.

A second limitation was that in this study design the IR-pass filter was manually held in place when measuring the consensual accommodative response. This allows possible human error to affect data measurement as it is impossible to ensure the filter was held in the exact same position and angle. This variation could affect the accuracy and variability of measurements through the filter, but we do not believe that this is the case in our study. As Figure 5 above demonstrates, the consensual response in both the SED and non-SED eye shows the same positive relationship between accommodative demand and amount of lag present in both the binocular and direct responses, which are not affected by the filter. If the variation in tilt was significantly affecting the measurement, we would not expect the patterns to be as similar as they are. It is also important that this same positive relationship was present when looking at the MED data in Figure 7 above as well.

Another limitation is the number of participants in the study. With the current data it appears as though there could be a slight interaction between eye dominance and accommodative response, but statistical analysis shows this relationship is not significant. However, if the study had more subjects and more data, this interaction could become more apparent and have statistical significance. Lastly, the target position during measurement of the consensual accommodative response is a limitation. The WAM-5500 allows for attachment of a central fixation rod that allows the accommodative target to move with the machine. This means that for each accommodative measurement the target was at 20cm directly in front of the eye being measured. This becomes a potential problem while measuring the consensual accommodative response as the eye being measured is not the eye viewing the target and driving the accommodative response. As demonstrated in Figures 2 and 3 above, this causes a slight increase in the viewing distance of the target by the fellow eye. This is important because the extended viewing distance causes a slight decrease in accommodative demand, and therefore likely stimulates a lesser accommodative response. If a lower accommodative response is measured, this would cause the amount of calculated lag to be greater than what is actually present based on the adjusted accommodative demand. This difference could contribute to the finding that the amount of lag was greatest under the consensual test condition.

Conclusions

This study examined the relationship between eye dominance and accommodative response under various test conditions using the WAM-5500 open-field autorefractor. No significant differences in accommodative lag were observed between the two eyes sensory or motor eye dominance. However, a significant interaction was discovered between the various testing conditions, with the consensual accommodative response having a higher lag than that present with direct and binocular accommodative conditions.

This study could be viewed as a pilot study on how to measure the accommodative response under various test conditions. A possible next step could be to design a study looking at the relationship between the accommodative response under the three test conditions in individuals diagnosed with accommodative dysfunction conditions. Understanding these relationships could have clinical relevance as the testing could be used in the diagnosis and management of accommodative dysfunction.

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