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Ocular sensory dominance and viewing distance

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I would like to thank and acknowledge the support and encouragement to persevere in the pursuit of my degree by Dr. Bin Zhang.

I would also like to acknowledge and thank Nova Southeastern University for recognizing the importance of research in the field of optometry and giving a home to those optometrists who wish to further the field of knowledge within the vision science community.

TABLE OF CONTENTS

Abstract

Purpose: It is not clear as to whether sensory dominance is affected by test distance. Jiang et al previously reported that that the sensory dominant eyes may be affected by refractive error; however this study was done at a near distance only (60 cm). In this study, we investigated the effect of two different test distances (near, 60 cm vs distance, 6 meters) on the laterality of ocular dominance.

Methods: Ocular sensory dominance was quantified in 60 subjects with a technique that involves the dichoptic presentation of a Mondrian noise and a Gabor patch. The threshold to detect the Gabor patch was measured in the presence of decreasing contrast in the Mondrian stimulus. Each eye was tested 50 times and thresholds from two eyes were compared with t-test. If the difference between the two eyes was significant, a subject was classified as having clear ocular sensory dominance and the eye that had lower thresholds was defined as the dominant one. If difference between the two eyes was not significant, a subject was classified as having unclear ocular sensory dominance. Ocular sensory dominance was measured at two different viewing distances, one for near at 60cm away and the other one for far at 6m away.

Results: In 31 subjects (51.7 %), dominant eyes remained the same for near and distance viewing. In 15 (25.0 %) subjects, who showed clear ocular sensory dominance at distance, ocular sensory dominance became unclear at near. In 11 (18.3 %) subjects, that had unclear ocular sensory dominance at distance, showed clear ocular sensory dominance at near. In 3 (5.0 %) subjects, the laterality of the dominant eye switched between far and near distance.

Conclusions: The effect of viewing distance on ocular sensory dominance is a continuous spectrum. In majority of the population, ocular sensory dominance is not affected. In 43.3 % of the population, ocular sensory dominance varies between unclear and clear status. Only in very rare cases, laterality of dominant eyes switches between near and distance.

List of Figures

Chapter 1: Introduction

1.1 Ocular Dominance in the literature

Ocular dominance can be referred to as a preference of one eye over the other during binocular tasks (1). While a person may have normal visual acuity and function in both eyes, some people have a tendency to still prefer the visual input from one eye over the other. Ocular dominance is a concept that people of all backgrounds may be familiar with, however the mechanism for ocular dominance is not well understood (2).

Ocular dominance relates to the development of one eye having a stronger cortical representation than the other. This manifests in many ways: A strong preference with visually guided tasks, such as "sighting through a gunsight" or visual guidance when the binocular system is not intact (1). Ocular dominance is not a monocular phenomenon; that is, it does not manifest only when the opposing eye is covered but is present when both eyes are being used (1).

Ocular dominance has been a concept that has been long studied, however due to variation in testing techniques and differences in laterality, progress in truly understanding ocular dominance has been slow (3). There are several issues that have contributed to this issue including testing methods. One theory that has been widely accepted is that laterality and handedness are intertwined when discussing ocular dominance (4). Physiologically and anatomically there is no scientific basis however it has become rote that these two features run hand in hand (2). This has also been extrapolated to include the "better seeing eye" is also dominant and related to sidedness, however this has not been proven to be an effective or consistent measurement of ocular dominance. Patients who suffer vision loss from trauma or retinal disease may prefer their worse seeing eye despite poor acuity (1).

1.2 Ocular Dominance: The Challenges

There are several misconceptions on how ocular dominance can be assessed from person to person (5). Ideally, a single test would give consistent and repeatable information however a consistent and repeatable screening test has not been shown to demonstrate laterality of ocular dominance (5). Clinical tests to assume ocular dominance have been helpful in some cases to determine refractive correction for monovision patients or prescribing ocular devices in low vision patients, however most of the tests performed are relating to sighted dominance (3,5). Other tests used for determining dominance are "rules of thumb" but there is no physiological explanation nor are they consistent and repeatable. Such tests include using which hand one uses for writing as an indication of laterality of ocular dominance or using which eye is "harder to wink" as an indication which eye is stronger (1,5). After image testing has also been used as a test for dominance**,** however patients with macular pathology may also demonstrate a longer photostress due to an irregularity in the cone function rather than any indication of ocular dominance. While anecdotally these tests may give rise to clinical prescribing practices, there is not much weight in the actual validity or any research to show these are reliable tests to use for measuring true ocular dominance (1,5).

In cases of visual acuity testing, different testing methods may explain some of the variability in results. Some variance in previous studies may be related to variability in acuity charts when it is assumed that visual acuity may influence ocular dominance (6). Pointer feels that true dominance may be confused by the use of differences in definitions of what true dominance is and how to utilize the best tests to obtain true results (6). Patients may perform better on one form of visual acuity testing vs another independent of consideration of performance due to ocular dominance testing (5,6). To explain, Pointer provided the example of someone who prefers to kick a ball with one foot but prefer to hop on the other; that is, the activity chosen to participate in will influence the outcome. Additionally, in addition to visual acuity, visual perception may have an effect on dominance (7). Thus, sighting dominance should be considered a different entity than visual acuity dominance (6).

Another issue that plagues understanding of ocular dominance is a lack of understanding of the different types of ocular dominance and how each can affect different aspects of visual function. Optometrists and ophthalmologists utilize certain techniques to ascertain which eye is dominant based for purposes of contact lens fitting, for lasik or cataract surgery (3). Unfortunately, using what are traditional ocular dominance measures, primarily using sighting dominance technique, doesn't always predict the outcomes patients experience in real world activities. The first step to understanding why variances in outcomes and requires a review of the different types of dominance (3,6).

1.3 Types of Ocular Dominance

There are three types of ocular dominance: Motor dominance, sighting dominance and sensory dominance (5). All three of these forms vary in testing methods and understanding how these forms vary contribute to an understanding of what testing method is most appropriate (3,5).

1.4 Motor Dominance

Motor dominance occurs when there is an asymmetry of vergence eye movements (5). For example, the dominant eye will maintain fixation on an object of interest while the other eye diverges. Motor dominance is likely influenced by innervation and muscular tonus where there is an imbalance between the eyes that influences ocular choice (1,5).

Furthermore, Wall suggested that motor dominance can be further divided into "secondary directional dominance" where the eye that diverges less is the eye looking at a close target (3 inches in this study) or "Master Eye Dominance" where the eye that is directly in front of the card, which has a hole in the center, helps in the primary function of "maintaining spatial localization and vergence and binocularity is maintained by the non-dominant eye" (1,8). Neither of these subdivisions of motor dominance have been found to be a consistent and reliable measure of ocular dominance according to studies by Wall and Gronwell and Sampson (1,8).

1.5 Sighting Dominance

Sighting dominance is likely the most common form of determining ocular dominance clinically for optometrists and ophthalmologist (3,5). When assessing a patient's suitability for monovision contact lens fitting or cataract surgery, tests of sighting dominance are often employed (5). A common sighting test includes having a patient align a distance target between their hands and compare the position of the distance target when either eye is closed; the open eye that has the target aligned centrally is considered the dominant eye (1).

While this is a common practice, it does not necessarily give a good assessment of true ocular dominance and other factors should be considered. Sighting preference may be related to true ocular dominance or it may be related to a circumstance outside one's control, such as pathology or injury to a previously dominant eye or a physical weakness or barrier that does not allow the patient to use their preferred eye (1). Wall gives the example of sighting through a gun barrel being limited by the design of the gun; a person who is left eye dominant may only be able to use his or her right eye due to the design of the sighting mechanism built on the gun (1). The argument becomes is this a motor function or sensory perceptual dominance. Likely sighting dominance is more a function of motor control than sensory because a patient may lay preference with the poorer seeing eye in sighting tasks (7).

1.6 Sensory Dominance

Sensory dominance is demonstrated under binocular conditions when one eye assumes a preference over the other (11). When presented with dissimilar images, the eyes will demonstrate rivalry and the eye with the stronger image will demonstrate sensory dominance (11). There is evidence that multiple factors may influence sensory dominance: visual field, contrast, strabismus and refractive error (11,12, 13, 14). This study will investigate sensory dominance specifically.

Different types of dominance may overlap or may create differences in ocular dominance readings in the same patient (8,9). Sensory dominance may demonstrate one eye to be dominant over the other while motor dominance testing may reveal a different finding. It is imperative for the clinician to utilize and interpret the appropriate test that uncovers the specific type of dominance they are looking for. A common clinical example is the frustration doctors encounter when fitting patients with monovision contacts using a sighting technique, and then watch the patient struggle with adaptation to their new prescription while performing activities of daily living (10).

1.7 Anatomy

It has been demonstrated that in the visual cortex of rats, the ocular dominance columns are separated and therefore the sensory input from each eye is distinct. The hypothesis of plasticity of ocular dominance has been questioned in the adult human, and plasticity may be related to the "distance between the ocular columns and any potential interconnections of neurons", usually due to some form of deprivation (15). Most research shows changes in ocular dominance is related to plasticity as a long term process secondary to deprivation or blurred vision creating a potential for permanent change (15).

Assessment of the anatomical arrangement of cortical hemifields as they correlate to retinopic organization has shown that there is some asymmetry during assessment of patients' cortical visual fields during a functional MRI using traditional retinopic stimulation. There appears to be more asymmetry within subjects when measuring the boundaries of the right hemisphere compared to the left. While supported by the use of fMRI measurements, there is some variability and limitations when using this method and correlation to other studies may be limited due to testing methods. (16).

According to a study by Rademacher r et al in 1993, only an 8% difference in size between the two hemispheres has been found. A later study found that while there is a noted difference in size between the left and right hemisphere, the mean volume is approximately the same (16). This contradicts pervious fMRI studies that find the left size is consistently larger and does not support an increase in neurons in either hemisphere (16).

The study by Zhang demonstrates that differences exist in the cerebral hemisphere maps. The most distinct difference being along the vertical meridians. This is notable because this forms the boundaries between the different hemispheres and may explain whys some variability may exist in laterality. There is also a possibility that this is how both hemispheres work in complimentary roles. While it was not shown that significant retinopic differences exist relating to normal anatomic variances, there is some support that said anatomical differences may relate to different strength of lateral hemispheric fields (16).

This study also demonstrates that while eyes operate as singular organs there is some yoked properties that may correlate to a left or right visual field dominance rather than a true right or left eye dominance (1,16).

It has been long assumed that each person has one eye that is dominant for all tasks, however this concept has since been disproven. It has been demonstrated that one may demonstrate unclear dominance under certain conditions, such as changes in viewing distance or refractive error Most of the literature that supports the use of dominance relating to one eye is usually referring to sighting dominance, however this theory has also been disproven (2).

Crossed dominance may occur when dual organs change dominance in certain conditions. The resultant effect may be a reduction of coordination of the two organs (1). Ocular dominance differs in that while eyes are “paired”, visual input into each eye is independent. The nasal field is paired with the opposing eye's temporal field, which influences visual dominance as well as motor dominance (1). The concept of "holocularity" , that is, perceptually when a whole eye (nasal and temporal fields of one eye) discovered by Jasper and Raney helps describe this concept (1). When presented with a light at a near distance (38 cm) and intermediate distance (142 cm), subjects were assessed as to whether they experience "Phi apparent movement" when the light changed from distance to near. Upon alternation, some patients noted a "movement" of lights and the apparent movement (from right to left or vice versa) could be assumed to be related to dominance of the lateral retina that is more dominant. (1).

1.8 Visual Development

Ocular dominance columns appear early in the development of the visual system. The critical period is that time during development where the "axons are susceptible" to manipulation from different forms of stimulation (17). Neural models have shown that ocular dominance is formed from the "segregation of axons from the lateral geniculate nucleus" in layer four of the primary visual cortex (17). The lateral geniculate nucleus (LGN) is organized into 6 separate layers that coordinate visual information from the retina to the visual cortex. These layers coordinate information from the ipsilateral eye (2,3,5) and the contralateral eye (layers 1, 4, 6). (18). Columns become more discrete with maturity and overlap to some extent in developing eyes. Dominance patterns are related to different types of neuronal activity that specialize axons into "eye-specific domains."

The density of neurons in layer four has been found to be unequal however due to a low number of axons in this area, it is difficult to determine if differences and fluctuations are due to undeveloped or developing ocular dominance columns. The strength of ocular dominance has therefore been suggested to be related to visual demands and visual activities during the critical period (17). Ocular dominance columns have been assumed to be formed during visual activity during the critical period and is less influenced after the critical period has ended. Variances in "retinal activity" on developing ocular columns have not been found to have a physical or structural effect on dominance columns or any "rewiring". In a study comparing neural organization of ferrets with monocular enucleation during the critical period compared to after the critical period, significant reorganization of the lateral geniculate nucleus axons in the visual cortex occurs while visual deprivation occurs during the critical period. Post critical period however, structurally there is not a significant change in the organization of lateral geniculate axons in the visual cortex post monocular enucleation. Therefore it is hypothesized that the most significant impact retinal imagery has on development of ocular dominance is during the critical period (17)

The concept of variable dominance is not new, however, it has been difficult to pinpoint what visual conditions may alter dominance. The challenge lies in the determination of what constitutes a test to measure dominance: one that measures ocular motor response, one that measures visual acuity, etc. (1) Ocular dominance can vary over time and activities and visual stimulation may also influence ocular dominance to change (3). The purpose of this study is to assess the effect of test distance on sensory ocular dominance.

Chapter 2: Methods

2.1 Subjects

A total of 60 subjects, 15 males and 45 females, were recruited from the clinic of Nova Southeastern University. The ages ranged from 21-32 years of age with mean age of 23.7 +/-2.2 years. To be included in the study, the subjects were required to have best corrected visual acuity (BCVA) of 20/20 or better at distance for each eye. Subjects were excluded from the study if any of the following conditions existed: latent hyperopia, history of strabismus or ptosis, any ocular surgery, amblyopia, keratoconus, glaucoma, retinal diseases, optic disc abnormalities, optic neuropathy, or other diseases that might affect BCVA, and any obvious facial asymmetry that could be easily identified by visual evaluation.

The study was approved by the Ethics Board of Nova Southeastern University. Informed written consent was obtained from the subjects after explanation of the nature and possible consequences of the study. All procedures adhered to the Declaration of Helsinki of the World Medical Association.

2.2 Measurements

The method used in this study to measure sensory dominance was a modified version of the method developed by Yang and Blake and used by Jiang et al in their assessment of sensory dominance in patients with aniesometropia (13). Stimuli were presented in the center of a CRT (1024 x 768 resolution; 100 Hz; Gamma corrected for linearity, Richardson Electronics) against a uniform background (mean luminance 50 cd/m2) and viewed at a distance of 60 cm with a chin rest. Distance testing was then performed at 6 meters.

The dynamic Mondrian patterns subtended 4.3° x 4.3°, with individual elements extended 0.154°. The target stimulus was a Gabor patch tilted 45 degree toward either the right or the left (SF = 1c/d, spatial extension 1.9°). The black and white strokes that framed the Mondrian and Gabor were 0.33° in width and were used to help achieve binocular fusion. Mirrors were used to present the Mondrian and target stimuli dichoptically. Each eye exclusively viewed one of the two stimuli during a given trial. The eyes viewing the dynamic Mondrian and target stimuli were counterbalanced and randomized across trials (Fig 1). The experiment was programmed in commercial software (MatLab, Version 2012Rb; The Math-Works, Natick, MA, and the Psychophysics Toolbox, Version 3).

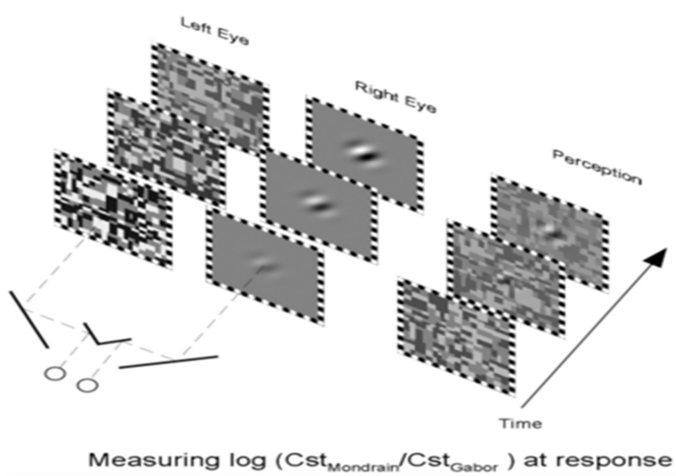


Figure 1. Method to test sensory ocular dominance. (Image from Jiang et al, Association between Ocular Sensory Dominance and Refractive Error Asymmetry PLOS ONE | August 21, 2015. 1-12, Used with permission from B.Zhang.)

At the beginning of a trial, the measured eye viewed the target Gabor patch at 0% contrast and the fellow eye viewed a full contrast Mondrian pattern. During a trial, the contrast of the Gabor patch linearly increased at a rate of 1% every 100 ms, and the contrast of Mondrian patterns linearly decreased at the same rate. The subjects were tasked with reporting, by pressing one of two keys, when the obliquely oriented Gabor patches were detected. A trial terminated once the response was made. For each trial, the log ratio of Mondrian to Gabor's contrasts [log (CstMondrian/CstGabor)] at the moment of response was computed. The higher the ratio, the greater the quantitative measure of the ocular sensory dominance of that eye. A high ratio means that the contrast detection threshold of the oriented Gabor patch needed to overcome the suppression imposed by the Mondrian stimulus on the other eye is low. In other words, the sensitivity of the eye with low contrast detection threshold, in overcoming Mondrian suppression, is high. All the subjects performed 10 practice trials before starting 50 experimental trials. Testing time per subject was approximately 15 minutes.

2.3 Statistical Assessment

T-test was used to compare the 50 values collected for each eye. T-value, which is the interocular difference in mean values normalized by the standard deviations of values from both eyes, was used as the ocular dominance index (ODI) to quantify a subject's overall degree of ocular dominance. An ODI value of 2, which corresponds to a p value of 0.05 at a sample size of 50, was selected as the significance level. An ODI less than 2, was regarded as having an unclear dominance. A subject with an ODI greater than 2 is regarded as having clear sensory. All ocular dominance tests were conducted by Dr. Bin Zhang.

Chapter 3: Results

3.1 Statistics

SPSS19.0 software (IBM, USA) was used for statistical analysis. The paired t-test was used to compare the dominant eye differences at two distances between the subjects. By Bootstrap repeated sampling 1000 times more close to the dominant eye, respectively, tend to strong eye and weak eye offset difference. All 60 participants completed the entire study.

3.2 Viewing distance and ocular dominance: Qualitative Analysis

Thirty one (31) out of 60 (51.7%) subjects had no change in laterality of ocular dominance when comparing distance to near targets. Of these, 31 subjects 13 (41.9%) had unclear dominance at distance and near while 17 (48.3%) maintained right sided dominance at distance and near. Four subjects (9.7%) demonstrated left sided dominance for all tasks. Figures demonstrating typical responses for all combinations of ocular dominance are included in Appendix A.

In 15 out of 60 subjects (25.0 %) ocular dominance was definitively measured at distance however became unclear at near. Of the 15 subjects, 13 (86.7%) changed from right eye dominant at distance and demonstrated unclear dominance at near, while the remaining 2 subjects (15.3%) were left eye dominant at distance and became unclear at near.

In 60 subjects, 11 (18.3%) demonstrated unclear dominance at distance and developed right or left eye dominance at near. Four (36.4%) of these subjects demonstrated right eye dominance at near while 7 (63.6%) demonstrated left eye dominance at near.

In only 3 cases (5%) dominance changed in laterality from distance to near. In two subjects (66.7%), ocular dominance changed from right eye at distance to left eye dominance at near. In the remaining one subject (33.3%), dominance changed from left eye at distance and right eye at near.

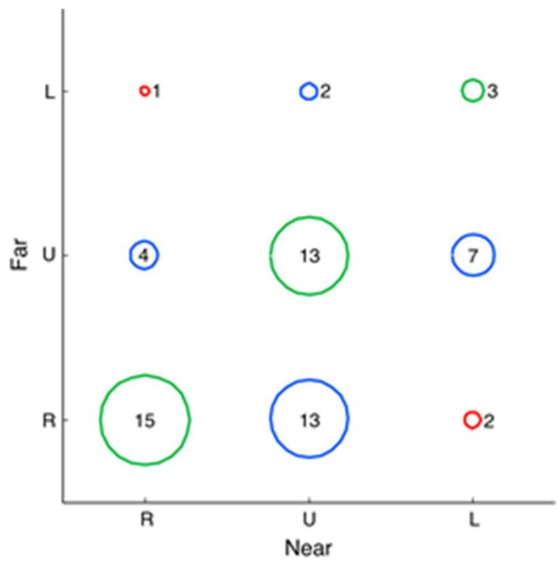


Figure 2. Summary map showing the distribution of ocular dominance at far and near. Green circles represent the cases in which the ocular dominance is consistent. Blue circles represent the cases of transition from having clear dominance at one distance and no clear dominance at another distance. Red circles represent the cases that have dominant eye swapped.

3.3 Viewing distance and ocular dominance: quantitative analysis.

Quantitative analysis showed that the mean Ocular Dominance Index (ODI) of all subjects changed from a -1.88 ± 2.71 at distance to -0.72 ± 2.95 at near. This indicated that the dominance of the right eye at distance was reduced and changed to show two more evenly balanced eyes at near (T = 2.84, p <0.0062) **(Fig. 3A).** When changing from the distance to near, most of the subjects (45 subjects, 75%) showed ocular dominance shift towards the originally weaker eye. Only a small number of subjects (15 subjects, 25%) had ocular dominance further shifted towards the originally stronger eye (**Fig 3B).** The mean ODI shift towards the originally weaker eye (2.66 ± 0.32, CI: 2.03 to 3.31) which was significantly greater than ODI shift towards the originally stronger eye (1.04 ± 0.25, CI: 0.54-1.52). The difference was statistically significant (p <0.01) (**Fig 3C).**

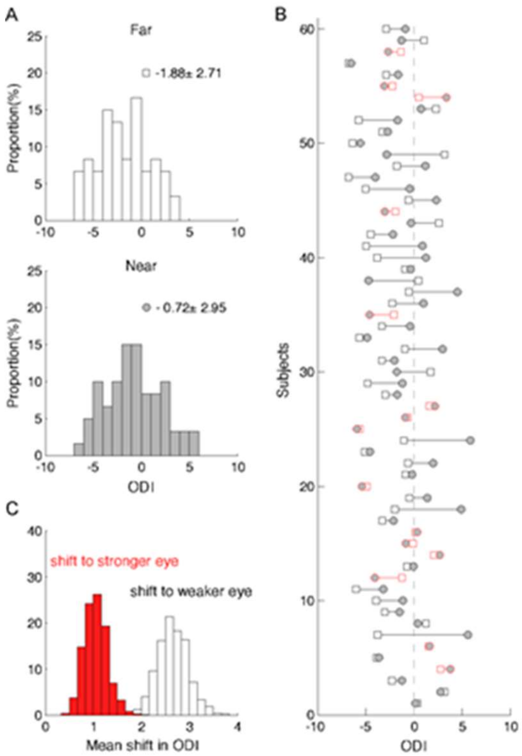


Figure 3: Ocular dominance and viewing distance. (A) ODI distribution at far (white histogram) and near (gray histogram). (B) Changes of ODI from distance to near. For those shifting towards the originally weaker eye, white square represents far and gray circle represents near. For those shifting towards the originally stronger eye, red square represents distance and gray circle with red outline represents near. (C) Bootstrap repeated sampling showing the amount of shifts towards the stronger eye (red bars) and towards the weaker eye (white bars).

Chapter 4 : Discussion

This study is the first of its kind in evaluating specifically sensory dominance in subjects at two different viewing distances, 60 cm and 6 m. This has shown that testing distance may have an effect on sensory dominance, another key to understanding ocular dominance as a whole. There are a few key points that this study has demonstrated.

There is a difference in the prevalence of laterality of dominance depending on what type of dominance is being measured. An interesting point to be made is 25% of subjects (15 out of 60 subjects) demonstrated right side only dominance at distance as well as near. This is a significant difference in the population as prior studies that have utilized sighting dominance tests found approximately 59-66% % of people are right eye dominant (3). There is a significant difference in dominance laterality when using different methods to assess different dominance types. Additionally, at near distances, ocular dominance is more balanced, thus giving the patient more opportunity for stereopsis and balance while reading.

Clinically, optometrists and ophthalmologists utilize sighting dominance tests to determine refractive correction for patients who are presbyopic or pseudophakic. Patients may be fit with mono-vision correction, that is, fitting the eye that is dominant with a distance contact lens and the non-dominant eye with additional plus correction to allow for near tasks (3,10). Additionally, ophthalmologists performing cataract surgery correct with the same strategy to give patients some near correction instead of fully relying on reading glasses. In cases where this strategy is employed, patients do not always adapt to this correction despite showing a strong dominance to a particular eye in the distance sighting test (10). In cases where there is not success in this prescribing strategy, there is rarely further attempts to reassess dominance or a different assessment of measuring dominance. While further study would need to be conducted, changes in sensory dominance in patients with adaptations to monovision refractive correction may uncover potential changes in neuroplasticity as patients adapt to new prescriptions.

Furthermore, in clinical practice of low vision, the effects of sensory dominance can confound performance with prescribed assistive devices. The majority of optical devices are prescribed for monocular use and are prescribed for use with the better seeing eye. At times, patients complain of a doubling of vision which can confound what appears to be a straightforward rehabilitation plan. It would be difficult to utilize the same protocol used in this research project to assess sensory dominance in individuals with visual impairments due central and peripheral vision loss, however, the information gleaned from this study can be used as an educational tool and explanation of why this phenomenon occurs in these patients.

In Jiang et al's study regarding anisometropia and sensory dominance, it was found refractive error effected a difference in ocular dominance in that anisometropia does have an effect on ocular dominance preferences (13). Eyes that are more myopic or less hyperopic have a tendency toward increased ocular dominance. Further evaluation on refractive error and its effect on ocular dominance at different test distances may differentiate some patients who have changes in ocular dominance at different test distances.

Chapter 5: Conclusion

This study has shown that test distance may have an effect on sensory ocular dominance in some cases. In most subjects' laterality remained unchanged at the two target test distances, in some cases unclear dominance became clear when test distance changed, and finally in a few cases laterality changed when test distance changed.

Appendix A

Figure 4.

Example of Patient with right eye dominance at distance and near

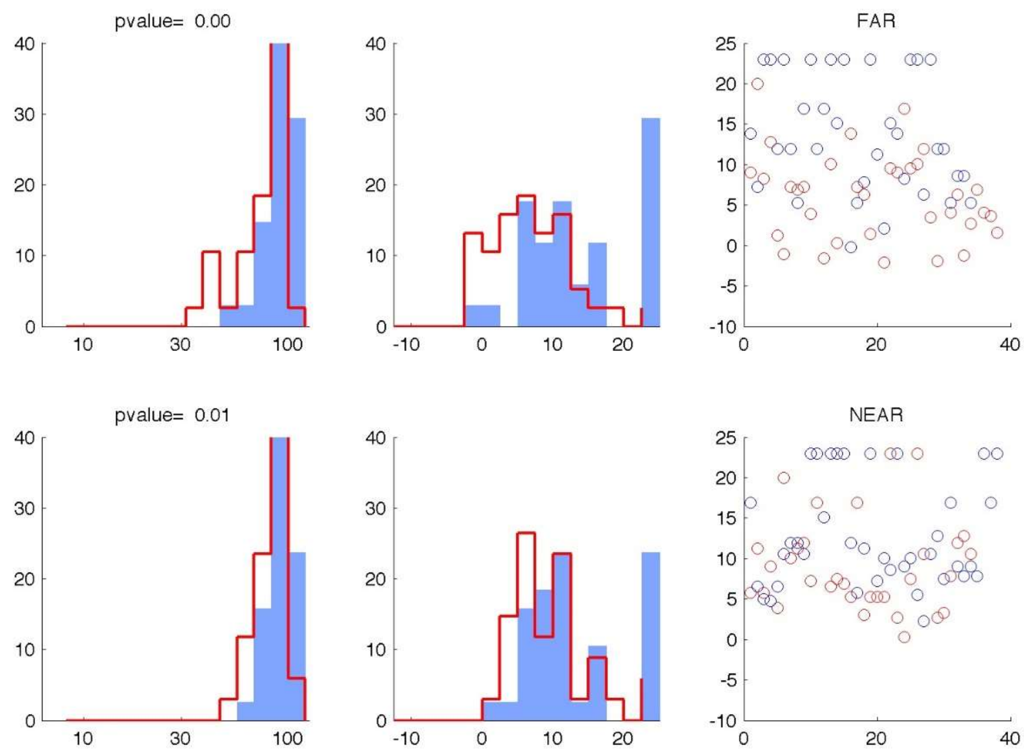


Figure 5.

Patient demonstrating left eye dominance at distance, left eye dominance at near

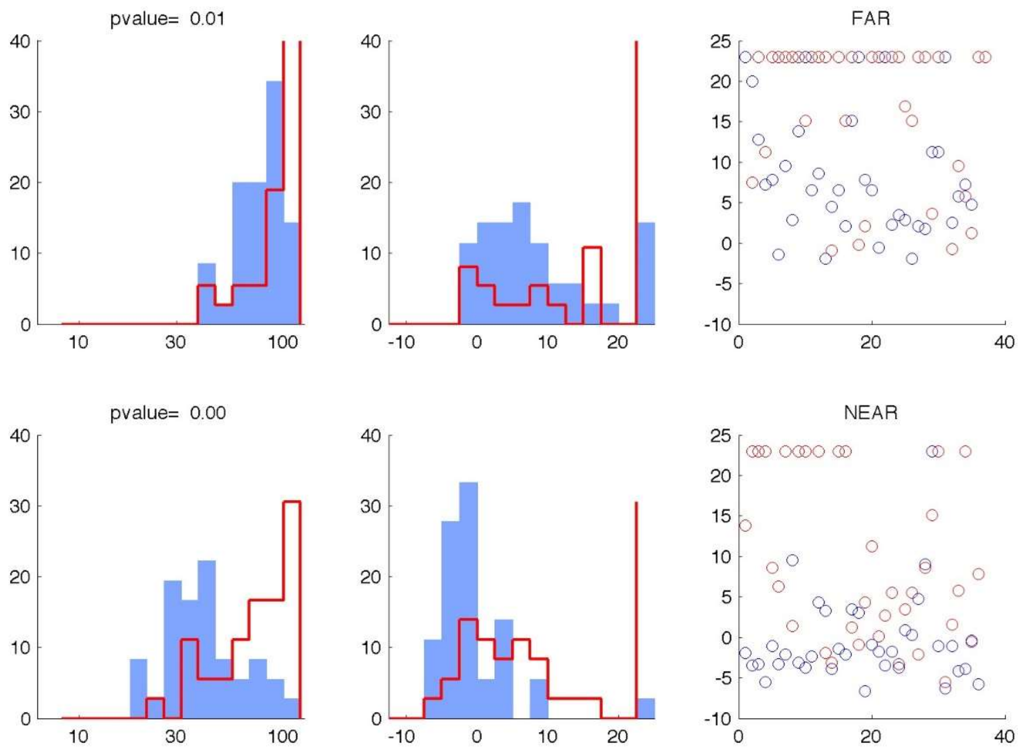


Figure 6.

Patient demonstrating right eye dominance at distance, unclear dominance at near

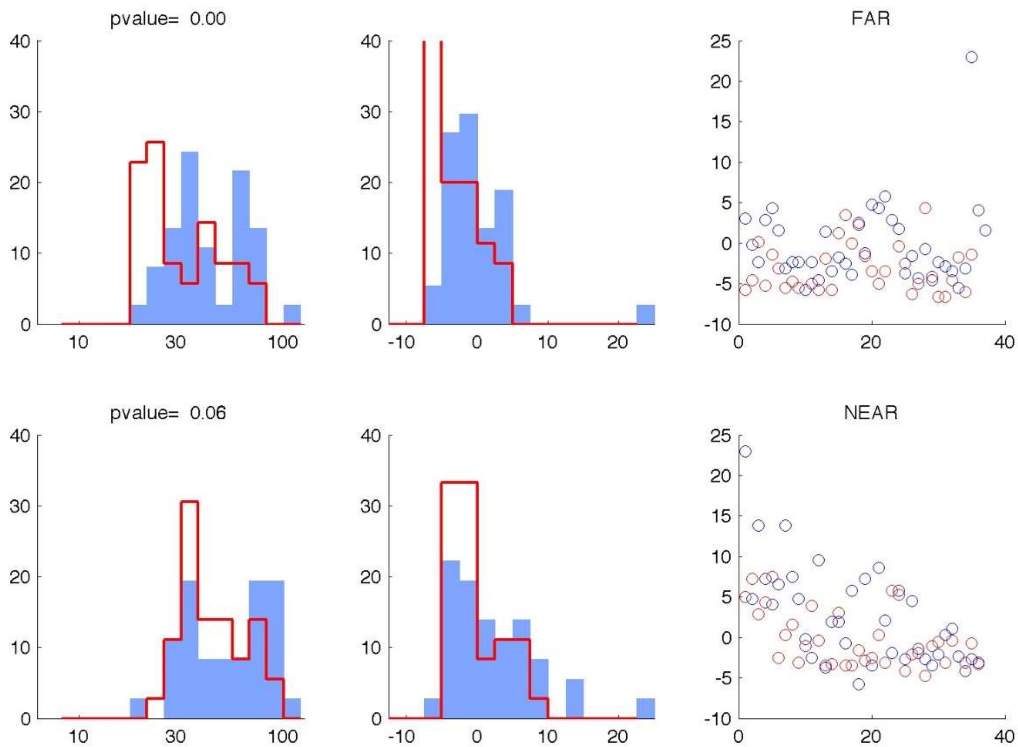


Figure 7.

Patient demonstrating unclear dominance at distance, right eye dominance at near

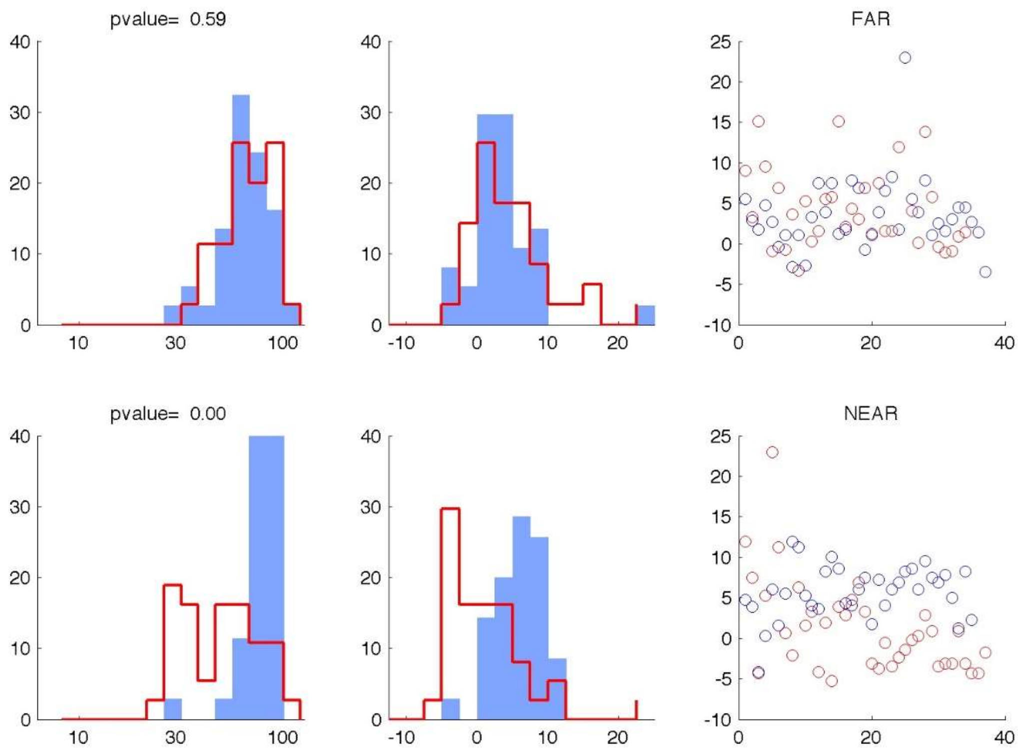


Figure 8.

Patient demonstrating rating left eye dominance at distance, unclear dominance at near

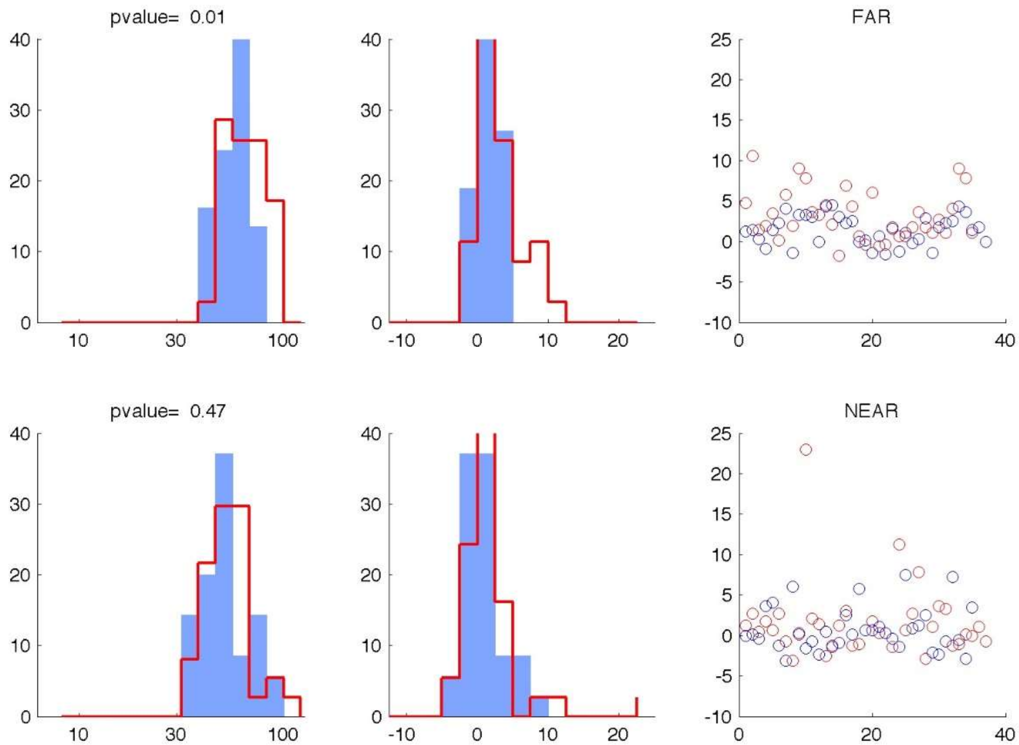


Figure 9.

Patient demonstrating unclear dominance at distance, left eye dominance at near

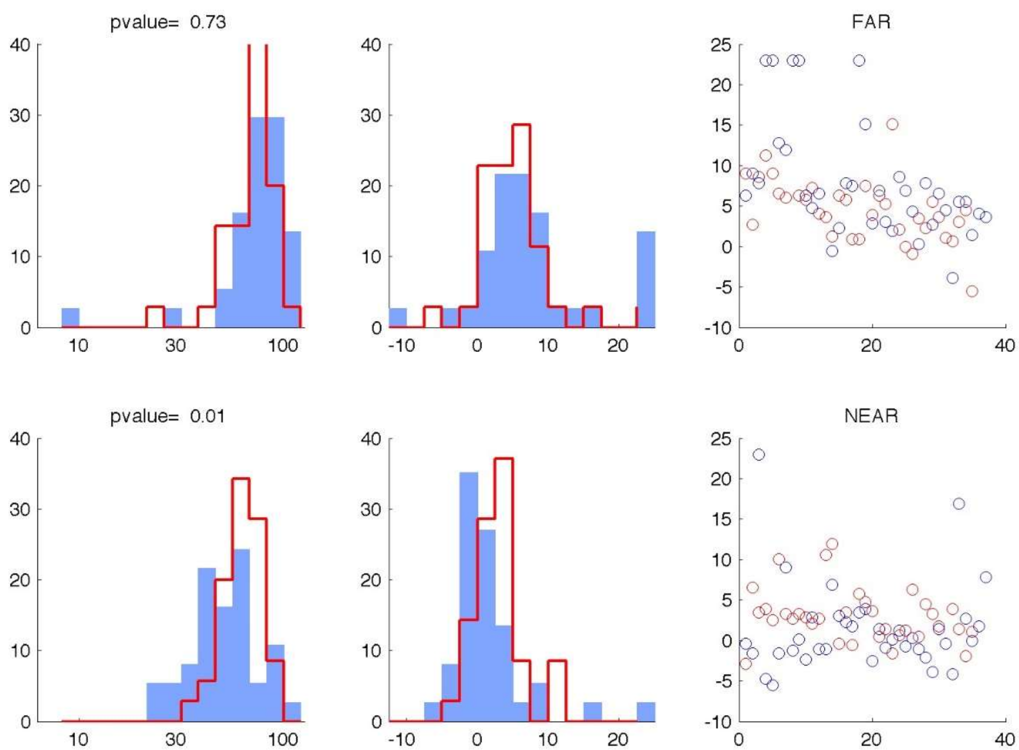


Figure 10.

Patient demonstrating right eye dominance at distance, left eye dominance at near.

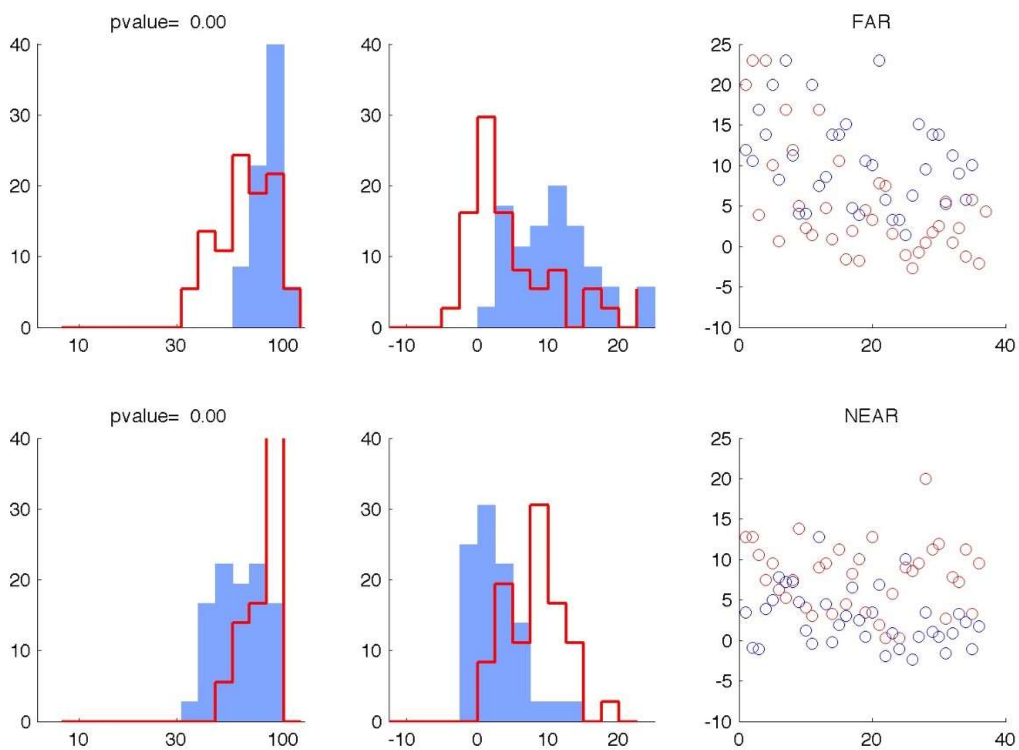


Figure 11.

Patient demonstrating unclear dominance at distance and near

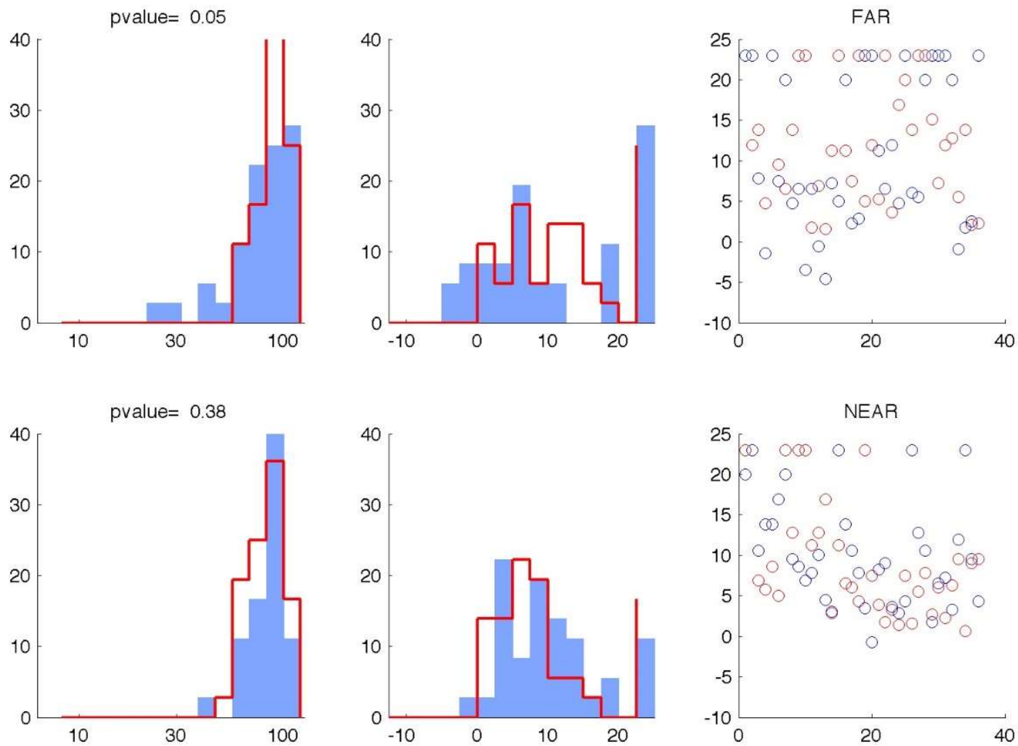
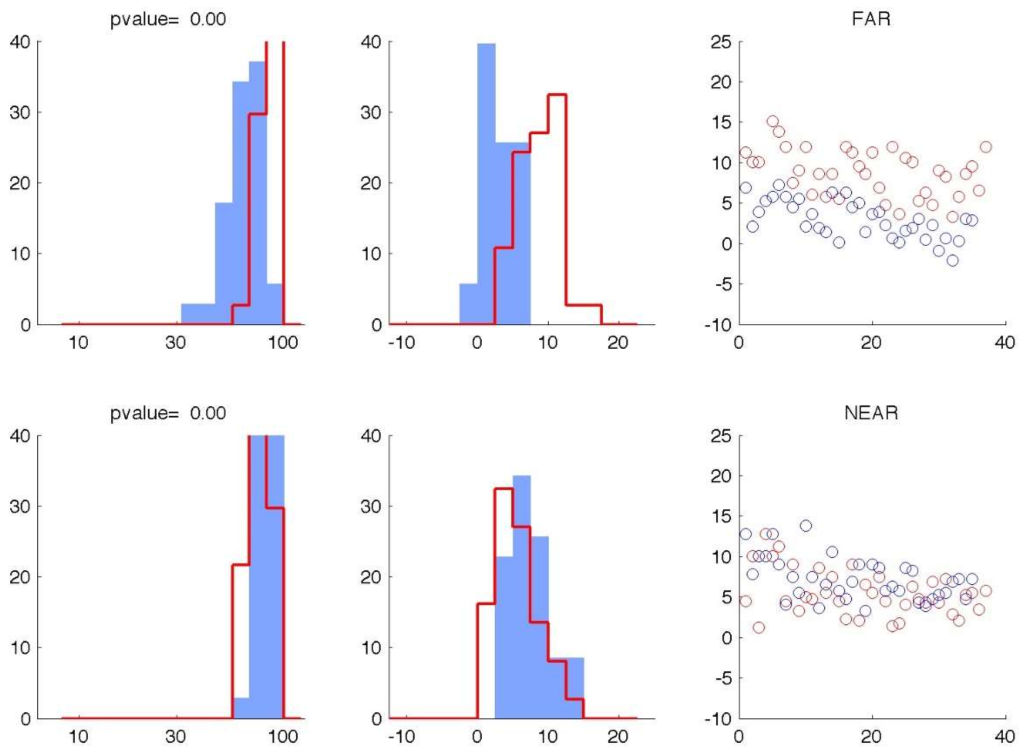


Figure 12.

Patient demonstrating left eye dominance at distance, right eye dominance at near



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