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ABSTRACT

LONGITUDINAL INVESTIGATION OF DISPARITY VERGENCE IN YOUNG ADULT CONVERGENCE INSUFFICIENCY PATIENTS

by
Patrick C. Crincoli

Vergence is a form of eye movement in which the eyes move in opposite directions to minimize retinal disparity. It allows an object at different distances from a viewer to appear single during binocular vision by centering the image on the fovea of each retina. Convergence insufficiency (CI) is a binocular disfunction in which blurry and double vision is a symptom. Office-based Vergence/Accommodative Therapy (OBVAT) has been shown to be effective in treating CI. A randomized clinical trial was designed to study fifty participants with CI before and after therapy using randomized therapy treatment (active and placebo), standardized clinical definitions, and a masked clinician to measure clinical outcomes. A haploscope was used to independently show stimuli to the left and right eye of the participants. A video-based eye tracker was used to capture eye-movement data, and a custom MATLAB program was used to analyze the following data parameters: latency, time to peak velocity, peak velocity, and final amplitude. Eye-movement data parameters significantly improved post OBVAT when comparing baseline and post treatment results. The results after Office-Based Placebo Therapy (OBPT) were compared to OBVAT results, and a statically significant difference was found. Results support that OBVAT leads to a significant improvement in vergence dynamics post therapy compared to baseline measurements.

LONGITUDINAL INVESTIGATION OF DISPARITY VERGENCE IN YOUNG ADULT CONVERGENCE INSUFFICIENCY PATIENTS

by
Patrick C. Crincoli

A Thesis
Submitted to the Faculty of
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Master of Science in Biomedical Engineering

Department of Biomedical Engineering

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APPROVAL PAGE

LONGITUDINAL INVESTIGATION OF DISPARITY VERGENCE IN YOUNG ADULT CONVERGENCE INSUFFICIENCY PATIENTS

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For my family, Ivan, Nikky, and Maria, who believed in me when I could not.

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LIST OF SYMBOLS AND TERMS

CI	Convergence Insufficiency
CISS	Convergence Insufficiency Symptom Survey
CITT	Convergence Insufficiency Treatment Trial
DAQ	Digital Acquisition
°	Degrees
Δ	Diopters
D	Diopters
FFPS	Fast-Fusional Phasic System
FIC	Fusion Initiating Component
FSC	Fusion Sustaining Component
HBCVAT+	Home-Based Computer Vergence/Accommodative Therapy & Pencil Pushups
HBPP	Home-Based Pencil Pushups
IPD	Inter Pupillary Distance
NPC	Near Point of Convergence
NIH	National Institutes of Health
OBPT	Office-Based Placebo Therapy
OBVAT	Office-Based Vergence/Accommodation Therapy
PFV	Positive Fusional Vergence
SFTS	Slow-Fusional Tonic System
TBI	Traumatic Brain Injury

CHAPTER 1

INTRODUCTION

1.1 Objective

The objective of this study is to determine the effectiveness of office-based vergence/accommodation therapy (OBVAT) compared to office-based placebo therapy (OBPT) for participants with symptomatic convergence insufficiency (CI). Clinical measures currently used to diagnosis and quantify convergence insufficiency by optometrists are employed in this randomized clinical trial to evaluate therapy effectiveness. Additionally, metrics from eye movements captured with an assessment protocol using a haploscope are utilized to demonstrate therapy effectiveness. The next few sections will give important background information describing the human visual, oculomotor, and vergence systems, as well as convergence insufficiency and the Convergence Insufficiency Treatment Trial, a related study on OBVAT and OBPT.

1.2 The Visual System

Sight is a critical sense for the modern human, used to examine one's surrounding, reading, learning and more. Sight is made possible by a complex visual system dependent on a pair of light-sensitive organs, the eyes. A thin layer covers and lines the eye called the conjunctiva, a mucus membrane [1]-[4]. The eye is composed of three layers: the sclera and cornea, the choroid, and the retina [1]-[4]. The sclera is the white outer layer of the eye, surrounding it and giving it shape [1]-[4]. The cornea is the front protective and refractive outer layer of the eye, which helps to focus light as it enters the eye [1]-[4]. The

choroid is a pigmented highly vascularized middle layer providing nutrients to the eye [1]-[4]. The retina, the inner layer of the eye, receives light and converts it to neural signals [1]-[4]. Figure 1.1 shows the basic anatomy of the eye.

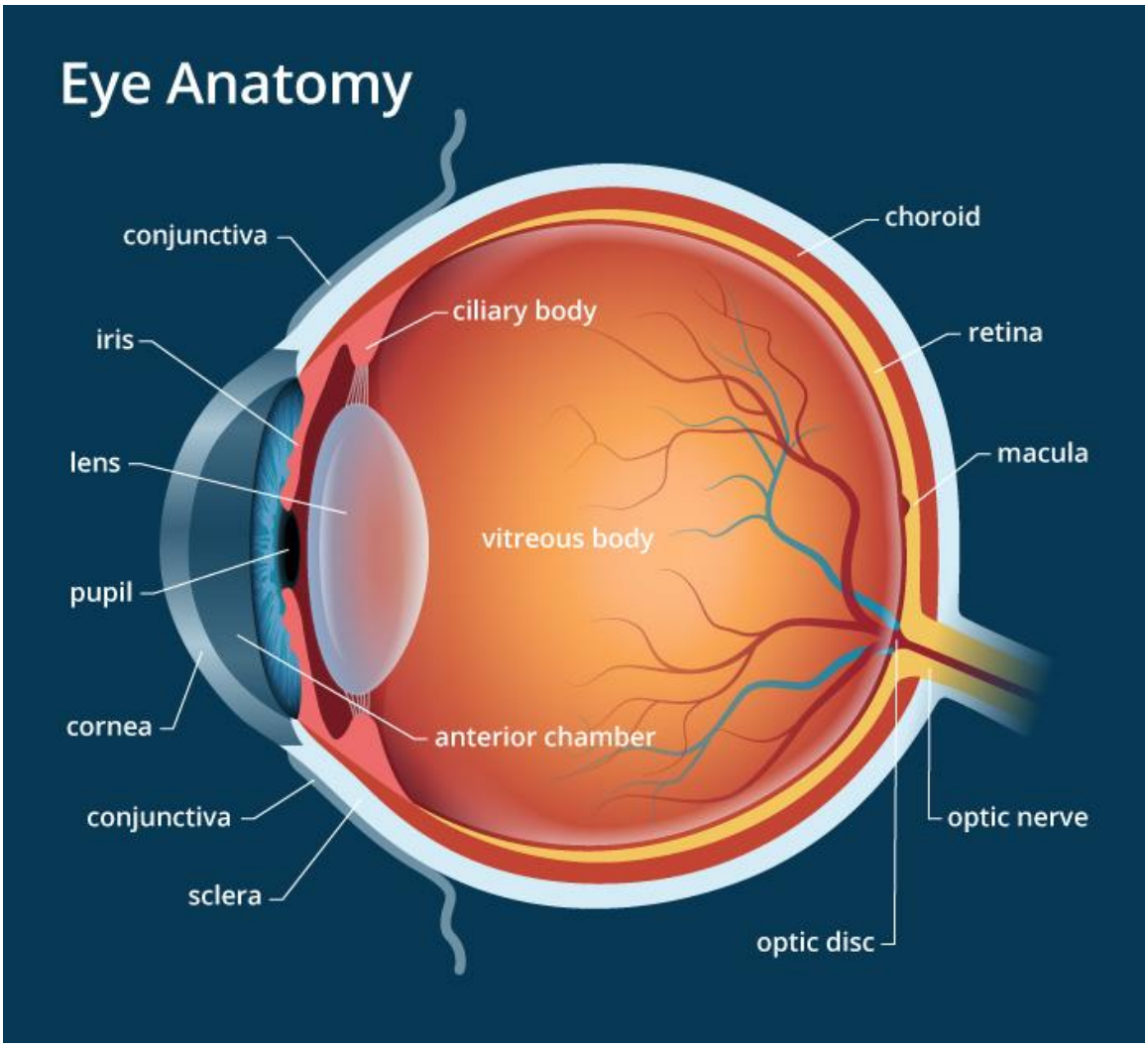

Figure 1.1 Diagram of basic eye anatomy.
Source: [1]

Light enters and is focused by the cornea. The pupil is a hole in the eye which allows light to pass to the back of the eye. The iris controls the amount of light that enters the pupil. The ciliary body controls the lens to focus light onto the macula, a region on the back of the eye and retina [1],[3],[4]. At the center of the macula is the fovea, surrounded by the parafoveal region. The fovea is responsible for high acuity vision and has a high

concentration of photoreceptors, especially cones [3],[4]. Figure 1.2 shows the path of light entering the eye as well as the anatomy of the eye.

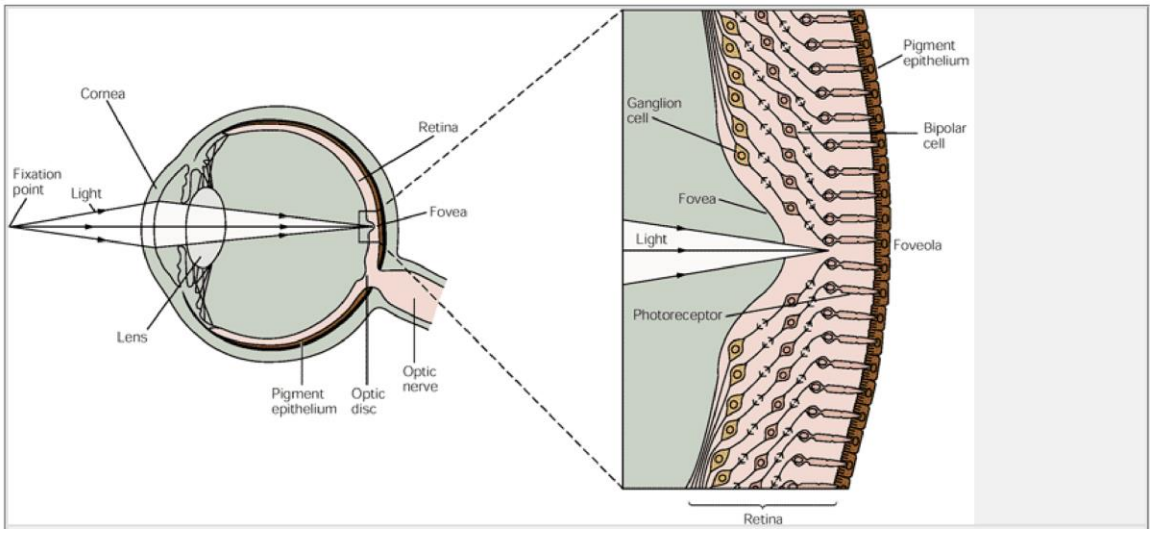

Figure 1.2 Diagram of light entering the eye with detail of retina.
Source: [4]

The retina is composed of three groups of cells: photoreceptors, interneurons, and ganglion cells [4]-[6]. Photoreceptors are the outer layer of cells which transduce light to an electrical signal. There are two types of photoreceptors, rods and cones. Rods have a low acuity and high sensitivity, amplifying light signals more than cones and functioning in dim light [4]. Cones have a high acuity and low sensitivity, functioning in day light enabling form and color perception [4]. Interneurons help transmit signals from photoreceptors to the ganglion cells. There are three types of interneurons: bipolar cells, amacrine cells, and horizontal cells [4],[5]. Ganglion cells respond to receptive fields, of which there are a multitude [4]. Figure 1.3 shows a diagram of the cells that make up the retina.

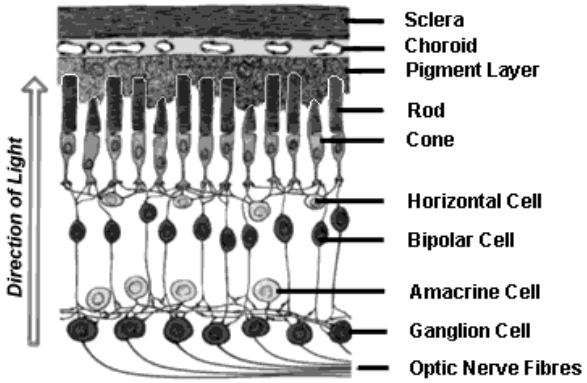

Figure 1.3 Diagram of the retina and the contained cell types.
Source [5]

Signals from the ganglion cells travel to the optic nerve [4]-[8]. The neural pathway from the eyes to the brain is called the afferent neural pathway. The optic nerve travels to the optic chiasm in the hypothalamus where half the axons from each optic nerve travel to the ipsilateral and the other half to the contralateral sides of the brain [4],[6]-[8]. The images from the left and right eye must be fused into a single and clear image. From here signals are transmitted to the lateral geniculate nucleus and finally the primary visual cortex in the occipital lobe where high-level visual processing occurs [4],[6]-[8] (Fig 1.4).

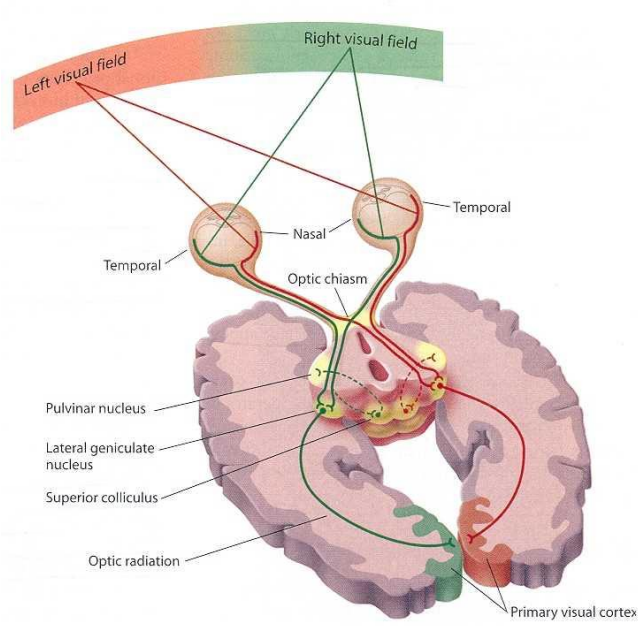

Figure 1.4 Diagram of the visual pathway.
Source: [7]

1.3 The Oculomotor System

The eye rotates within the orbit allowing for motion. Movement of the eye allows the fovea to be directed onto an area of interest and keep it steady [9],[10]. The eye moves using six muscles: the superior rectus, inferior rectus, medial rectus, lateral rectus, inferior oblique, and superior oblique [9],[10] (Fig 1.5). These muscles are controlled by three cranial nerves, efferent neural pathways sending signals from the brain to the muscles [9],[11]. The superior and inferior rectus move the eye upwards and downwards respectively [9],[10]. The medial rectus and lateral rectus move the eyes horizontally towards and away from the center of the body respectively [9],[10]. The superior and inferior oblique move the eyes clockwise and counterclockwise respectively [9],[10]. Eye rotation can be measured using diopters (Δ), degrees (°), or meter-angles. These muscles work together through different control systems to move the eye.

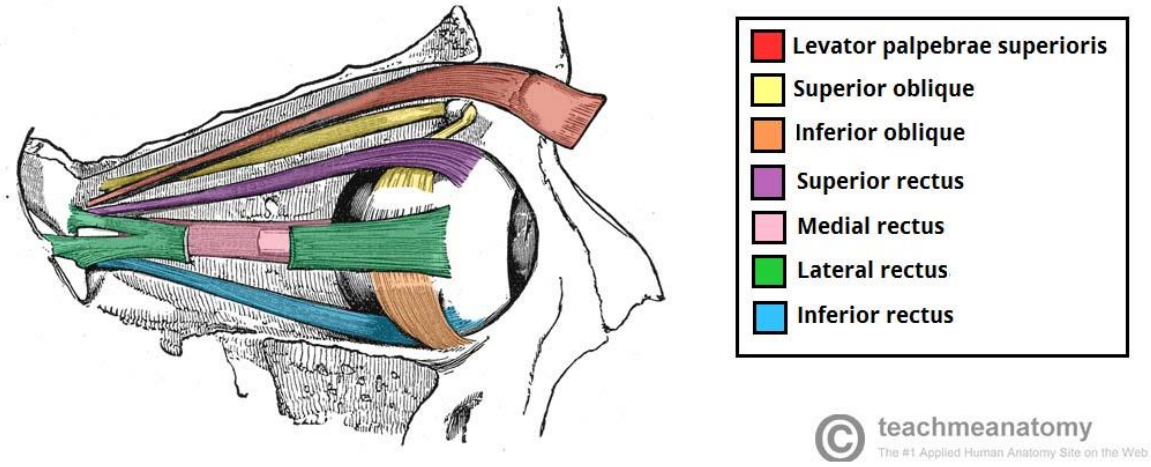

Figure 1.5 Diagram of the six eye muscles that control eye movement.
Source: [9]

There are six neuronal control systems used to keep the fovea on target. These are: saccadic eye movements, smooth pursuit movements, vergence movements, vestibulo-ocular movements, optokinetic movements, and the fixation system [4],[11],[12]. Smooth pursuit movements keep an image of a moving target on the fovea. Vestibulo-ocular

movements hold images still on the retina during head tilt using the vestibular system of the inner ear. Optokinetic movements hold images during sustained head rotation and are driven by visual stimuli. The fixation system holds eyes still, requiring active suppression of eye movement. Saccadic eye movements shift the fovea rapidly to a visual target in the periphery. Vergence movements move the eyes in opposite directions so an image is positioned on both foveae. Saccades are conjunctive (version), eye movements, as both eyes move in the same direction, whereas vergence movements are disjunctive, as the eyes move in opposite directions. Horizontal saccades and vergence movements use the same muscles, the medial and lateral recti [4],[11],[12].

1.4 The Vergence System

Humans use both eyes, binocular vision, to perceive depth [4],[11],[12]. The distance between each eye, inter pupillary distance (IPD), causes two distinct images to be captured, one by each eye. The brain merges these two images into a three-dimensional image. The final effect is called stereopsis. Fusion occurs when an object appears on the same spot on each retina allowing it to appear single. Saccades are used to move the eyes side to side conjunctively to focus on a target without accounting for the depth/distance from the subject [4],[11],[12]. Distinctly, vergence movements are used to move the eyes disjunctively to maintain eye alignment on a target at a depth/distance from the subject [4],[11],[12].

There are two types of vergence eye movements, convergence and divergence [4],[11],[12]. In convergence, the eyes move inwards towards a target closer to the subject. In divergence the eyes move outwards towards a target further from the subject. There are

four types of vergence: fusional, accommodative, proximal, and tonic [4],[11],[12]. Fusional vergence uses a disparity cue, the distance difference between an object on each retina. Accommodative vergence uses a blur cue, caused by focal length. Proximal vergence uses a combination of monocular cues, such as relative size, texture gradients, lighting/shading, perspective, occlusion, and motion parallax. Tonic vergence is the resting state of the eyes with no stimuli. The resting state of the eyes is also called the phoria. Phoria has different classifications: orthophoria, esophoria, exophoria, hyperphoria, or cyclophoria [4],[11],[12]. Heterophoria is a generic term used to describe conditions in which the eyes tend to drift from a target when the eyes are left without stimuli, dissociated, open-looped [13]-[17]. Orthophoria is when the eyes do not drift open-looped. Esophoria, exophoria, hyperphoria, and cyclophoria are the tendencies for the eyes to drift inwards, outwards, up or downwards, or clockwise or counterclockwise respectively [4],[11],[12].

In the literature, there is a large volume of research into the model-representation of the neural control of the disparity-vergence system [18]-[31]. Vergence can be defined with two systems, a fast-fusional phasic system (FFPS) and a slow-fusional tonic system (SFTS) [18]-[23]. The SFTS is the tonic vergence and phoria. The FFPS includes fusional, accommodative, and proximal vergence. One model of FFPS is the Dual Mode Model. In the Dual Mode Model there are two components, the fusion initiating component (FIC) and the fusion sustaining component (FSC) [18]-[23]. The FIC is preprogrammed component that allows the eyes to quickly move to the general position of the target [18]-[23]. The FSC is the feedback-controlled component that is slower and more accurate [18]-[23]. The FIC more substantially governs the velocity components of vergence movements (time to peak velocity, peak velocity and response amplitude) [18]-[23],[26],[30]. The FSC

more substantially governs the final position of the eyes fixated on the target (final amplitude) [18]-[23],[26],[30]. Figure 1.6 is a diagrammatic representation of the Dual Mode Model.

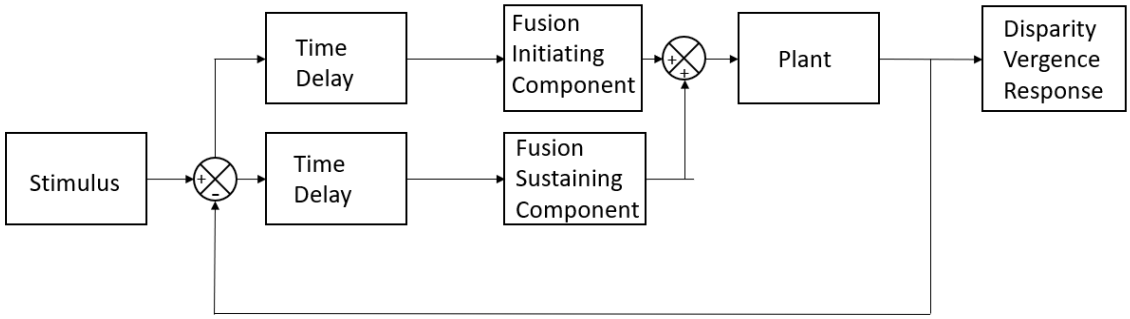

Figure 1.6 Diagram of the Dual Mode Model.
Source: [18]

1.5 Convergence Insufficiency

Binocular dysfunctions are conditions in which the eyes do not function correctly due to difficulty working together as a team. Convergence insufficiency (CI) is a specific binocular dysfunction, in which the eyes do not rotate sufficiently inward to maintain fusion of an image, especially with objects near to the person. CI affects approximately 5% of the human population, and over 50% of the traumatic brain injury (TBI) population [32]-[40]. Symptoms of CI can include double or blurry vision, headache, dizziness, or nausea when performing visual tasks close to the face [41]. Typically, a person with CI will have exophoria greater at near than at distance and one or both eyes will drift outward while working at near. CI can only be diagnosed by an eye care professional. Every routine eye examination will detect CI if the proper tests are done. In some routine eye examinations, the doctor may choose not to do any binocular vision testing. When this inadequate exam is performed, CI will not be detected. Standard measures of CI include a high score on the

Convergence Insufficiency Symptom Survey (CISS) (see APPENDIX A), a reduced near point of convergence (NPC), and a low positive fusional vergence (PFV). CISS is a survey intended to quantify symptoms of CI. Each response is rated from 0 to 4 with 4 as the highest frequency of symptom (always). There are 15 items which are totaled to get the CISS score. The lowest possible score is 0 (least symptoms) and the highest possible score is 60 (most symptoms). A score of 16 or higher has been found to indicate symptomatic CI in children, and a score of 21 or higher has been found to indicate symptomatic CI in adults. Treatments for CI include: home-based therapy solutions including pencil push-ups, or office-based vision therapy, or surgery rarely [32]-[40].

1.6 Convergence Insufficiency Treatment Trial

The Convergence Insufficiency Treatment Trial (CITT) led by study chair Dr. Mitchell Scheiman, O.D., Ph.D. assessed four different CI therapy methods: office-based vergence/accommodative therapy with home reinforcement (OBVAT), home-based pencil pushups (HBPP), home-based computer vergence/accommodative therapy and pencil pushups (HBCVAT+), and office-based placebo therapy (OBPT) [42]. CITT was a large-scale stage 3 randomized clinical trial funded through the National Institutes of Health (NIH) with 221 children participants ranging from 9-18 years of age. After 12 weeks of therapy, the OBVAT group had a statistically significant ($P<0.001$) decrease in CISS score, greater than the other therapy groups. Further, the OBVAT group, compared to other therapy groups, had a significant improvement in mean NPC and PFV at near. The study defined a "successful outcome" with a CISS <16, an NPC of less than 6 cm, and a PFV greater than 15Δ and passing Sheard's criterion. The study defined an "improved outcome"

with a CISS <16 or a 10-point decrease, and at least one of the following: NPC of less than 6 cm, NPC improvement of more than 4 cm, PFV greater than 15Δ, or an increase in PFV of more than 10Δ. The therapy groups had significantly different amounts of group members experience "successful or improved outcomes" with the OBVAT, HBPP, HBCVAT+, and OBPT, experiencing 73%, 43%, 33%, and 35% respectively [43][44].

This study attempts to build on the CITT findings by using latency, time to peak velocity, peak velocity, and final amplitude to evaluate OBVAT and OBPT in addition to the clinical measures above.

CHAPTER 2

METHODS

2.1 Participants and Screening

This study had a total of 50 participants aged between 18 to 35 years (inclusive), with symptomatic convergence insufficiency. Symptomatic convergence insufficiency was defined by 4 major criteria. First, a symptomatic score on the CISS (average score of 21 or higher). Second, a near point of convergence greater than or equal to 6 cm. Third, an exophoria at near greater than far by at least 4 prism diopters (Δ). Fourth, an insufficient positive fusional vergence defined as failing Sheard's criterion (30) or a positive fusional vergence of less than 15Δ base-out. Participants were required to have 20/25 visual acuity or better (with refractive correction if needed), no history of previous vision therapy, stable general health, intact cognitive function, and no other neurological conditions. A complete list of eligibility and exclusion criteria is included in Table 2.1. An informed consent was signed by all participants in accordance with the Declaration of Helsinki and approved by the NJIT review Board. Participants were randomly assigned to a therapy group, either OBVAT or OBPT using the CONSORT Agreement [45]. They were kept naïve to which group they were assigned to throughout the study.

Participants underwent an examination to determine eligibility. Clinical testing and measurements were taken in the following order: visual acuity, auto-refraction, stereopsis (Randot Stereotest), CISS, cover/uncover (unilateral cover) test at distance and near, alternate cover test with prism neutralization at distance and near, negative fusional vergence (blue, break, and recovery) at near, positive fusional vergence (blur, break, and

recover) at near, near point of convergence break and recovery, vergence facility at distance and near, push-up accommodative amplitude, accommodative facility (right eye only) with +2.00/-2.00 lenses.

The clinical outcome measures used were the CISS score, NPC, and PFV. The CISS was measured before and after all testing. An example of the CISS is shown in Figure A1. The NPC was measured with the Near Point Rule (Gulden Ophthalmics, Elkins Park, PA) with a printed Gulden fixation target consisting of a single column of 20/30 letters at 40 cm. The PFV was measured at near with a horizontal prism bar (Gulden B-16 horizontal prism bar levels from 1 Δ to 45 Δ, Gulden Ophthalmics, Elkins Park, PA) while the patient fixated a hand-held fixation target (Gulden Fixation Stick # 15302) with a single column of letters of 20/30 equivalent. The group values are summarized below in Table 2.2. All participant screening and clinical measures were performed by a licensed optometrist.

Table 2.1 Table of Eligibility and Exclusion Criteria for CI Participants

Eligibility Criteria for Convergence Insufficiency (CI) Participants
Age 18 to 35 years
Best-corrected visual acuity of 20/25 or better in both eyes at distance
Convergence Insufficiency Symptom Survey score ≥21
Exodeviation at near at least 4Δ greater than at far
Receded near point of convergence of ≥6 cm break
Insufficient positive fusional convergence (i.e., failing Sheard's criterion or ≤15Δ blur or break) on positive fusional vergence testing using a prism bar)
Random dot stereopsis appreciation of 500 seconds of arc or better
Wearing appropriate refractive correction (spectacles or contact lenses) for at least 2 weeks
Informed consent and willingness to participate in the study and be randomized
Exclusion Criteria for CI Participants
Constant strabismus at distance
Vertical heterophoria ≥2Δ at distance or near
≥2 lines interocular difference in best-corrected visual acuity
Accommodative amplitude <5 D in either eye as measured by Donder's push-up method
Manifest or latent nystagmus
History of strabismus surgery or refractive surgery
History of head trauma or known disease of the brain
Diseases known to affect accommodation, vergence, or ocular motility
Inability to comprehend and/or perform any study-related test

Table 2.2 Table of Participant's Averages for Clinical Values

	Age (years)	Gender	CISS	NPC (cm)	PFV (Δ)
OBVAT Participants	21.08 ± 3.60	14M, 11F	33.96 ± 8.97	10.52 ± 3.67	12.24 ± 3.18
OBPT Participants	20.64 ± 3.06	11M, 14F	35.12 ± 6.13	10.36 ± 3.32	12.84 ± 4.51

2.2 Experimental Setup

2.2.1 Instrumentation

The ISCAN RK-826PCI binocular tracking system (Burlington, MA) was used to record eye movements. The setup of the system is shown in Figure 2.1. The system used a central infrared emitter to envelop both eyes with light, then an infrared camera on either side of the face is used to record each eye. The infrared light was emitted at a wavelength of 950 nm and power of 1.2 mW/cm^2. This was considerably lower than the ANSI Z136 standard safety limit of 10 mW/cm^2. The pupils absorb the light, while the rest of the eyes reflect the light. The ISCAN software is used to locate the centroid of each pupil. Thus, the device is able to record pupil location and diameter, horizontal and vertical eye movements, and the movements of the reflection from the corneal surface. The manufacturer reports an accuracy of 0.3 degrees over a ±20 degree horizontal and vertical range. A 12-bit digital acquisition (DAQ) card (National Instruments 604 E series, Austin, TX) digitized the eye movement data recorded from the ISCAN instrumentation with a sampling frequency of 500 Hz. Two monitors and partially reflecting mirrors were used to present stimuli to the left and right eyes independently [46]. In totality this setup is referred to as a haploscope.

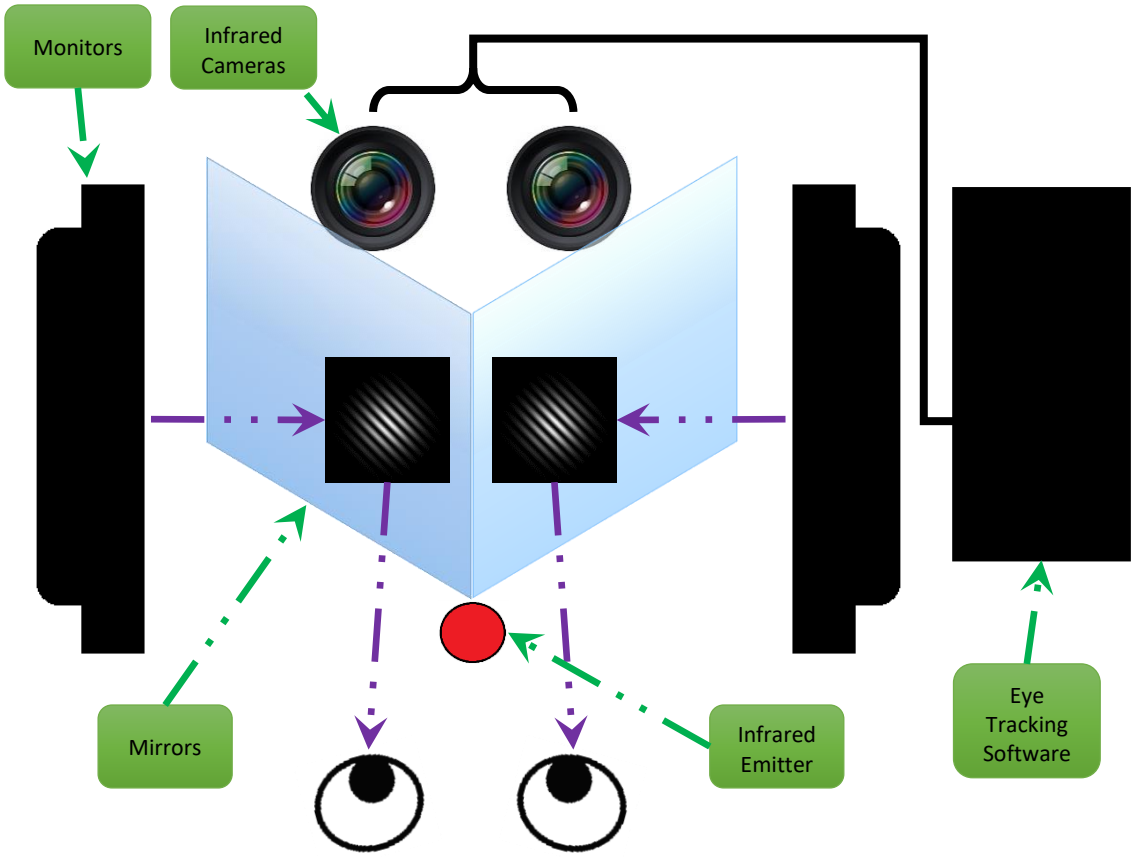

Figure 2.1 Haploscope experimental setup. The setup presents stimuli to the participant and collects eye movements.

2.2.2 Software, Stimuli, and Data Collection

VisualEyes, a custom LabVIEW™ (National Instruments, Austin, TX) program was used to control the stimuli presentation and data collection from the instrumentation. Digitized eye movement data was collected from the DAQ. Visual stimuli were generated on each monitor, that are then reflected to each of the participant's eyes using the mirrors. The visual stimuli are presented to the left and right eyes separately [46]. This simulates a symmetrical disparity vergence stimulus along the participant's midline. Accommodation is kept constant in this experiment by keeping the total distance from the stimuli to the eyes (focal length) to 40 cm (2.5D). The stimuli presented to the participant is a Gabor patch as seen in Figure 2.2. The Gabor patch is a low spatial frequency cue, meaning it has soft

edges with a slightly blurry look. It was held constant at a 2-degree eccentricity for height and width in a darkened room [47]. The Gabor patch kept at a constant distance and size was used to reduce blur and proximal cues [47]. The constant and reduced accommodative and proximal cues allowed this study to focus on examining the effects of disparity vergence.

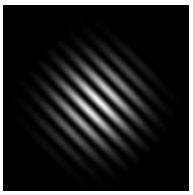

Figure 2.2 Gabor Patch. This image is used as the stimuli for the study.
Source: [48]

2.3 Experimental Procedure

2.3.1 Assessment Procedure

An assessment to determine changes in the vergence ocular motor system was created. Participants performed the assessment before and after the therapy procedure. The assessment was designed to be different from the therapy procedure to reduce possible procedure learning. Additionally, procedural learning was reduced due to the large time between assessments. The assessment procedure was standard for all participants and did not account for the individual's phoria level.

The assessment consisted of three sections: FAR, NEAR, and SACCADES. The FAR and NEAR sections are meant to simulate focusing on an object distant and close to a subject respectively. Before and after each section, a calibration was performed, then stimuli were presented, and eye movements were captured. A short break could be given to participants in-between sections. The calibration consisted of a 6-point monocular calibration in which 3 points were presented and recorded per eye, covering the range of

visual stimuli presented. There were three types of movements: disparity steps, disappearing steps, and saccades. Disparity steps and disappearing steps have vergence stimuli, where the stimuli on each screen move in opposite directions. Disparity steps begin at a certain position and instantaneously change to a different position. A disappearing step is the same as a disparity step, but the stimuli disappear 0.100 seconds after moving. Saccades are similar to disparity steps, however the stimuli presented to each eye move in the same direction. This was a version movement rather than a vergence movement. These movement types are shown in Figure 2.3. The order of movements was the same for all participants. However, this standard order was created in a randomized order to decrease participant learning and prediction and inhibit anticipatory movements. A complete list of movements is given in Table 2.3.

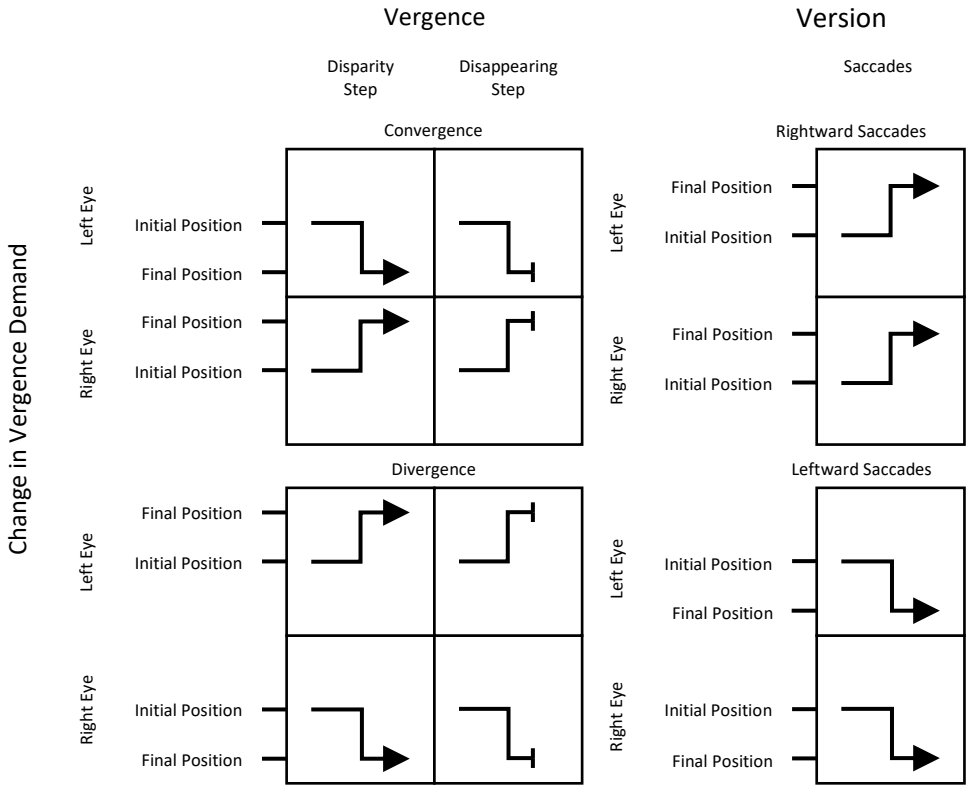

Figure 2.3 Diagrams of different movement types used as stimuli.

Table 2.3 Table of Movement Types

Section	Movement	Description	Analysis Group
FAR	CON48	Convergence, disparity step, from 4 to 8 degrees	CON4
	CON26	Convergence, disparity step, from 2 to 6 degrees	CON4
	CON28	Convergence, disparity step, from 2 to 8 degrees	CON6
	DIV82	Divergence, disparity step, from 8 to 2 degrees	DIV6
	DIV62	Divergence, disparity step, from 6 to 2 degrees	DIV4
	DIV84	Divergence, disparity step, from 8 to 4 degrees	DIV4
	DS_DIV84	Divergence, disappearing step, from 8 to 4 degrees	DSDIV4
	DS_DIV82	Divergence, disappearing step, from 8 to 2 degrees	DSDIV6
	DS_DIV62	Divergence, disappearing step, from 6 to 2 degrees	DSDIV4
	DS_CON48	Convergence, disappearing step, from 4 to 8 degrees	DSCON4
	DS_CON26	Convergence, disappearing step, from 2 to 6 degrees	DSCON4
	DS_CON28	Convergence, disappearing step, from 2 to 8 degrees	DSCON6
NEAR	CON812	Convergence, disparity step, from 8 to 12 degrees	CON4
	CON610	Convergence, disparity step, from 6 to 10 degrees	CON4
	CON612	Convergence, disparity step, from 6 to 12 degrees	CON6
	DIV128	Divergence, disparity step, from 12 to 8 degrees	DIV6
	DIV106	Divergence, disparity step, from 10 to 6 degrees	DIV4
	DIV126	Divergence, disparity step, from 12 to 6 degrees	DIV4
	DS_DIV126	Divergence, disappearing step, from 12 to 6 degrees	DSDIV6
	DS_DIV106	Divergence, disappearing step, from 10 to 6 degrees	DSDIV4
	DS_DIV128	Divergence, disappearing step, from 12 to 8 degrees	DSDIV4
	DS_CON612	Convergence, disappearing step, from 6 to 12 degrees	DSCON6
	DS_CON610	Convergence, disappearing step, from 6 to 10 degrees	DSCON4
	DS_CON812	Convergence, disappearing step, from 8 to 12 degrees	DSCON4
SACCADES	M2R5	Saccade, middle to right, 5 degrees	SAC5
	R2M5	Saccade, right to middle, 5 degrees	SAC5
	M2L5	Saccade, middle to left, 5 degrees	SAC5
	L2M5	Saccade, left to middle, 5 degrees	SAC5
	M2R10	Saccade, middle to right, 10 degrees	SAC10
	R2M10	Saccade, right to middle, 10 degrees	SAC10
	M2L10	Saccade, middle to left, 10 degrees	SAC10
	L2M10	Saccade, left to middle, 10 degrees	SAC10

2.3.2 Therapy Procedure

All participants took part in a total of 12 hours of office-based therapy and approximately 3 hours of home-based reinforcement therapy. Office-based therapy occurred once to twice per week, for about one hour per session, for 6 to 12 weeks. Home-based reinforcement therapy occurred three times per week for about 10 minutes per session on days without office-based therapy. Participants were randomly assigned to two therapy groups and participated in either OBPT or OBVAT. These therapies are identical to those performed in the CITT study [42][46][47]. The OBPT therapy was not designed to improve vergence or accommodation, but instead encourage the participants believe they were receiving the correct therapy. The OBVAT therapy was designed to improve both disparity vergence and accommodation. The OBPT therapy consisted of a combination of techniques that changed weekly: Necker Cube, HTS Placebo Accommodation and Vergence, Monocular Brock String, Visual Closure, Double Maddox rod, etc. Typically, these techniques are used to improve monocular inputs, eye focusing, ability to detect targets, visual response speed, eye teaming skills, and visual processing skills. The OBPT therapy schedule is shown in Figure 2.4. The OBVAT therapy had three phases. Phase one included techniques to improve gross convergence, positive fusional vergence, and monocular accommodative therapy. Phase two included techniques to improve ramp fusional vergence and monocular accommodative therapy. Phase three included techniques to improve jump fusional vergence and binocular accommodative therapy. Techniques included were Vectograms, Brock String, Barrell Card, Loose Lens Accommodative Rock, Letter Chart Accommodative Rock, Life Saver Cards, Eccentric Circles, HTS, etc. The OBVAT therapy schedule is shown in Figure 2.5.

Initial Training Visit

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Accommodation	8 minutes	Improve focusing and speed of response
Ductions	4 minutes	Equalize monocular inputs
Monocular Brock String – level one	6 minutes	Equalize monocular inputs
Visual Closure – Lines and Boxes	10 minutes	Eye teaming
At Home		
Monocular Brock String and TV Trainer	15 minutes	

Week 1

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Accommodation	8 minutes	Improve focusing and speed of response
Ductions	4 minutes	Equalize monocular inputs
Monocular Brock String –level two	6 minutes	Equalize monocular inputs
Visual Closure – Lines and Boxes	10 minutes	Eye teaming
At Home		
Monocular Brock String and TV Trainer	15 minutes	

Week 2

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Accommodation	8 minutes	Improve focusing and speed of response
Bailey-Lovie Acuity	4 minutes	Equalize monocular inputs
Monocular Brock String-level two	6 minutes	Equalize monocular inputs
Visual Closure – Closing on Center	10 minutes	Eye teaming
At Home		
Monocular Brock String and TV Trainer	15 minutes	

Figure 2.4a This is the first part of the OBPT therapy schedule.
Source: [49]

Week 3

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Accommodation	8 minutes	Improve focusing and speed of response
Bailey-Lovie Acuity	4 minutes	Equalize monocular inputs
Monocular Brock String – level three	6 minutes	Equalize monocular inputs
Visual Closure – Closing on Center	10 minutes	Eye teaming
At Home		
Monocular Brock String and TV Trainer	15 minutes	

Weeks 4 & 5

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Accommodation	8 minutes	Improve focusing and speed of response
After Image	4 minutes	Equalize monocular inputs
Red/Red Activities	6 minutes	Eye teaming
Visual Figure Ground – Hidden Characters (level 1)	10 minutes	Eye teaming
At Home		
HTS Vergence/Accommodation (or Red Lens Activities) and TV Trainer	15 minutes	

Weeks 6 & 7

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo vergence	8 minutes	Improve eye teaming and speed of response
Strobismo Trainer	4 minutes	Eye teaming
Yoked Prism Flippers	6 minutes	Eye teaming
Visual Figure Ground – Figuring Words (level 2)	10 minutes	Eye teaming
At Home		
HTS Vergence/Accommodation (or Red Lens Activities) and Polaroid Playing Cards	15 minutes	

Figure 2.4b This is the second part of the OBPT therapy schedule.
Source: [49]

Weeks 8 & 9

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Vergence	8 minutes	Improve eye teaming and speed of response
Modified Thorington	4 minutes	Eye teaming
Bernell-o-scope level 1	6 minutes	Eye teaming
Visual Spatial Skills	10 minutes	Eye teaming
At Home		
HTS Vergence/Accommodation (or Red Lens Activities) and Polaroid Playing Cards	15 minutes	

Weeks 10 & 11

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Vergence	8 minutes	Improve eye teaming and speed of response
Double Maddox Rod	4 minutes	Eye teaming
Bernell-o-scope level 2	6 minutes	Eye teaming
Visual Spatial Skills	10 minutes	Eye teaming
At Home		
HTS Vergence/Accommodation (or Red Lens Activities) and Polaroid Playing Cards	15 minutes	

Maintenance Therapy

Technique	Time	Goal
At Home		
TV Trainer	10 minutes	To improve eye teaming ability by using visual and motor inputs.
Polaroid Playing Cards	5 minutes	

Figure 2.4c This is the third part of the OBPT therapy schedule.
Source: [49]

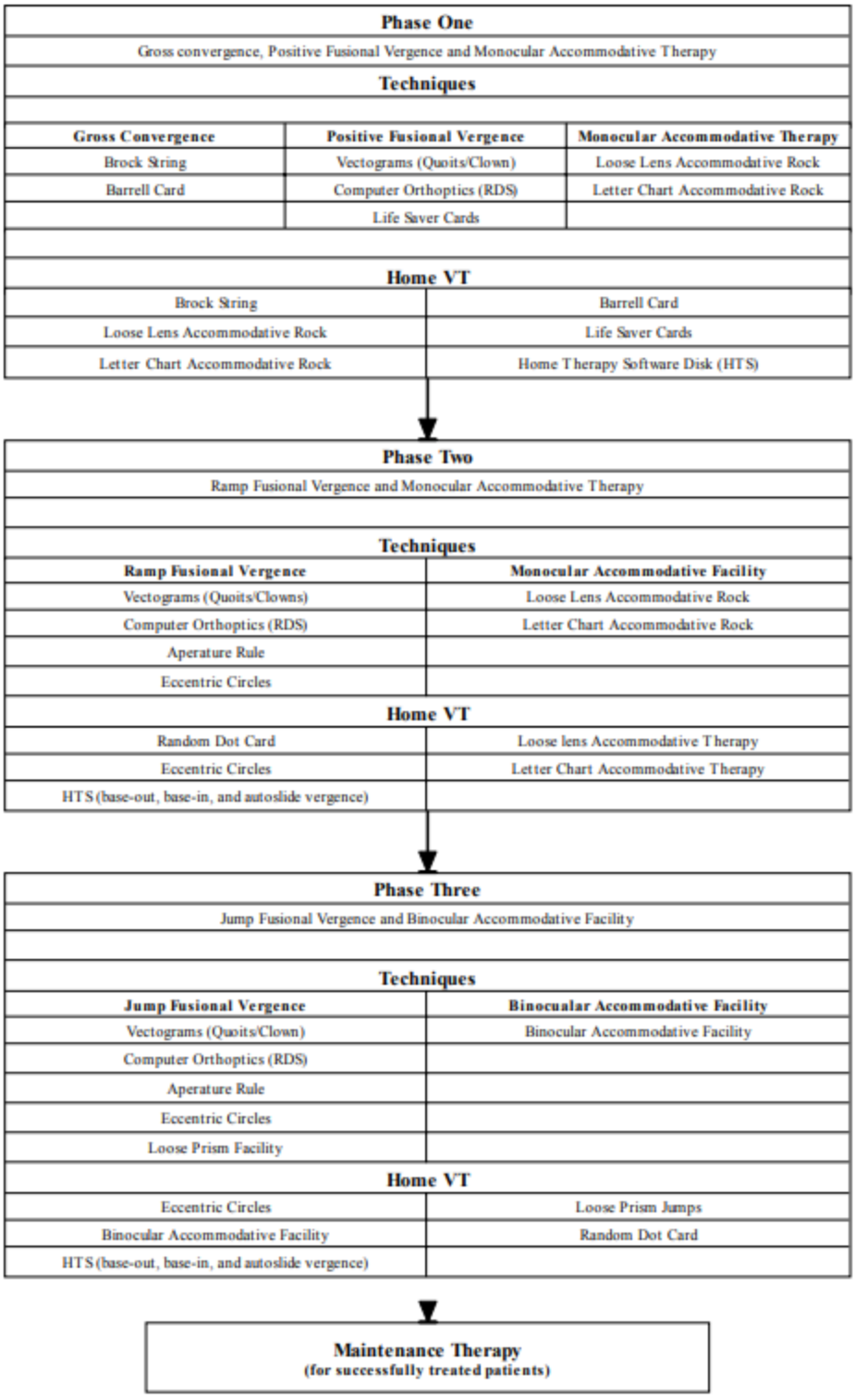

Figure 2.5 This is the OBVAT therapy schedule.
Source: [50]

2.4 Data Analysis

2.4.1 Data Processing

After eye movement data collection during the assessment procedure, the data was imported into MATLAB where it was analyzed. To calculate the vergence movement between the eyes, the raw right eye positional data was subtracted from the left eye positional data. For the FAR section the 1°, 3°, and 5° monocular calibrations corresponded to the 2°, 6°, and 10° binocular vergence angle demand. For the NEAR section the 4°, 5°, and 6° monocular calibrations corresponded to the 8°, 10°, and 12° binocular vergence angle demand. For the SACCADES section the 10° into left visual field, 0° on midline, and 10° into right visual field monocular calibrations corresponded to the 10° left, 0°, 10° right, binocular version angle demand. Eye movements that could not be analyzed due to saccade, blinks, etc. were removed. Outliers were removed (2 standard deviations away from the mean). Finally, similar movement types were grouped together for analysis.

2.4.2 Measures and Metrics

Four metrics were measured from the vergence eye movements: latency, time to peak velocity, peak velocity, and final amplitude. Latency is the amount of time from the stimuli to the start of the vergence eye movement. Time to peak velocity is the amount of time from the stimuli to the point at which the maximum velocity of the vergence eye movement. Peak velocity is the largest velocity during the vergence eye movement. The final amplitude is the final position of the eyes at the end of the vergence eye movement. Figure 2.6 A shows the position over time plot as well as the latency and final amplitude. Figure 2.6 B shows the velocity over time plot as well as the peak velocity and time to peak velocity. These values measured and compared before and after therapy, with therapy type

as OBPT or OBVAT, and between genders using a mixed ANOVA. After the mixed ANOVA, t-tests were performed.

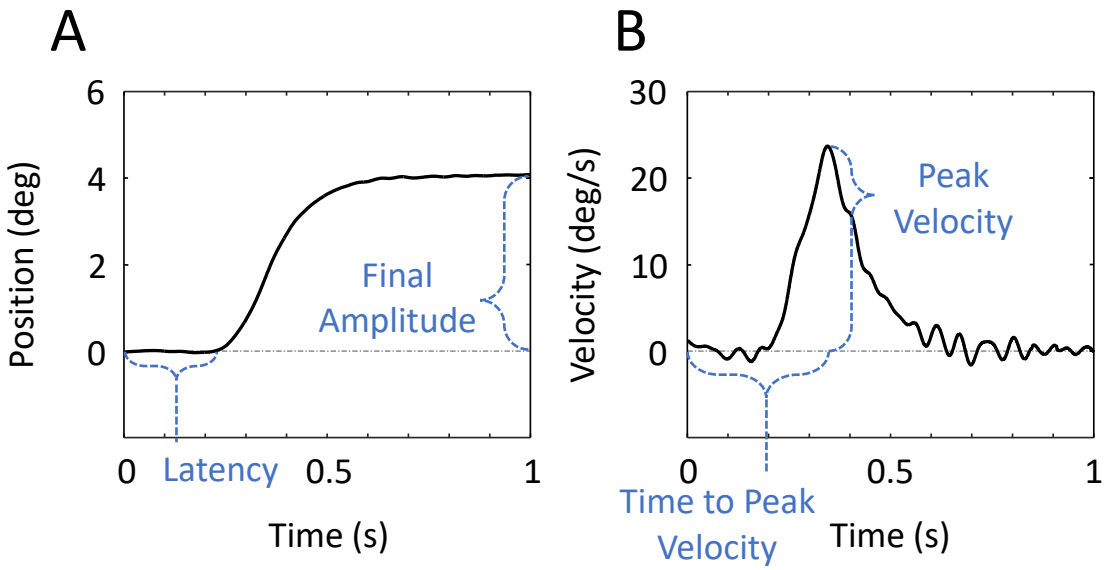

Figure 2.6 This figure shows a 4-degree convergence disparity step eye movement. Figure A is a Position over Time graph, and Figure B is a Velocity over Time graph of the same movement. Figure A shows the measured Latency and Final Amplitude. Figure B shows the measured Time to Peak Velocity and Peak Velocity.

CHAPTER 3

RESULTS

3.1 Clinical Results

Table 3.1 Table of OBVAT Participant's Clinical Values

Participant ID	Participant type	Therapy type	Age (years)	Sex	CISS Score		NPC (cm)		PFV (Δ)	
					Before	After	Before	After	Before	After
NIH032	CI	Active	19	M	34	28	6.5	3	10	20
NIH035	CI	Active	18	M	36	18	7.5	3	12	30
NIH042	CI	Active	18	F	25	23	13.5	7.5	14	16
NIH055	CI	Active	18	M	29	31	9	4	10	45
NIH081	CI	Active	19	M	30	15	13.5	4	6	50
NIH088	CI	Active	24	M	25	19	8	5	10	45
NIH103	CI	Active	18	F	33	29	7.5	4	18	35
NIH107	CI	Active	19	M	42	40	10.5	8	12	16
NIH110	CI	Active	25	M	37	21	8	3.5	12	45
NIH113	CI	Active	19	F	37	31	17	6	16	35
NIH118	CI	Active	21	M	30	16	21	3	6	50
NIH121	CI	Active	18	F	34	33	7	5	12	30
NIH125	CI	Active	21	M	32	24	9	8	12	25
NIH129	CI	Active	19	M	34	19	10	2.5	8	45
NIH138	CI	Active	25	F	21	24	7.5	5	12	45
NIH154	CI	Active	20	M	57	14	13	4.5	16	45
NIH164	CI	Active	22	F	23	16	14	5	10	25
NIH165	CI	Active	18	F	22	7	12	3	12	45
NIH167	CI	Active	19	F	47	18	9	3.5	14	30
NIH168	CI	Active	18	M	45	15	11	3	12	35
NIH169	CI	Active	25	M	47	34	9	5	14	30
NIH173	CI	Active	31	F	23	20	8.5	6.5	16	16
NIH176	CI	Active	25	F	42	18	8.5	3	18	50
NIH178	CI	Active	28	F	30	10	6.5	4	14	18
NIH187	CI	Active	20	M	34	18	16	4.5	10	35
Averages					33.96 ±8.97	21.64 ±7.99	10.52 ±3.67	4.54 ±1.60	12.24 ±3.18	34.44 ±11.66
Paired T Test (Within Participant) Significance					t=5.589 df=24 p<0.001		t=7.644 df=24 p<0.001		t=-8.602 df=24 p<0.001	

Table 3.2 Table of OBPT Participant's Clinical Values

Participant ID	Participant type	Therapy type	Age (years)	Sex	CISS Score		NPC (cm)		PFV (Δ)	
					Before	After	Before	After	Before	After
NIH038	CI	Placebo	26	F	26	23	13.5	10	25	18
NIH046	CI	Placebo	19	M	40	16	12	4.5	14	45
NIH105	CI	Placebo	18	F	42	20	14	6.5	16	25
NIH108	CI	Placebo	18	F	33	22	10	9	18	25
NIH111	CI	Placebo	23	F	40	26	8	4.5	8	25
NIH112	CI	Placebo	21	M	32	23	20	3	4	40
NIH115	CI	Placebo	22	F	42	38	8.5	4	8	30
NIH117	CI	Placebo	32	M	43	13	7	5.5	16	18
NIH119	CI	Placebo	19	F	43	24	7	7	14	25
NIH120	CI	Placebo	19	M	36	14	10	9.5	12	18
NIH122	CI	Placebo	20	F	36	44	8	2	16	25
NIH123	CI	Placebo	20	F	34	26	9	7.5	12	12
NIH124	CI	Placebo	19	F	30	29	9	8	14	20
NIH127	CI	Placebo	18	F	46	18	15	8	14	16
NIH133	CI	Placebo	18	F	31	31	12	9	10	14
NIH137	CI	Placebo	21	F	24	35	8	3.5	14	35
NIH140	CI	Placebo	18	M	35	20	12	8	10	16
NIH156	CI	Placebo	25	F	26	23	6.5	5	18	18
NIH162	CI	Placebo	28	M	40	22	14	3.5	16	14
NIH166	CI	Placebo	18	M	26	32	8	6.5	6	4
NIH170	CI	Placebo	20	M	38	41	14	10.5	14	16
NIH171	CI	Placebo	18	M	37	18	8	5	8	14
NIH172	CI	Placebo	18	M	31	30	11	9	12	16
NIH186	CI	Placebo	19	F	37	23	7.5	7	14	20
NIH191	CI	Placebo	19	M	30	23	7	5.5	8	25
Averages					35.12 ±6.13	25.36 ±8.02	10.36 ±3.32	6.46 2.38	12.84 4.51	21.36 ±9.04
Paired T Test (Within Participant) Significance					t=4.300 df=24 p<0.001		t=5.139 df=24 p<0.001		t=-4.126 df=24 p<0.001	

Table 3.3 Table of Unpaired T-Tests Between Therapy Groups

Independent Samples Test				
Clinical Measure	Time	t	df	p
CISS	Before	-.534	48	.596
	After	-1.643	48	.107
NPC	Before	.162	48	.872
	After	-3.351	48	.002
PFV	Before	-.544	48	.589
	After	4.432	48	.000

Table 3.1 has the clinical values for participants in the active therapy group. The active therapy CI participants have average values of 21.64±7.99 for CISS, 4.54±1.60 cm for NPC, and 34.44±11.66 Δ for PFV. Table 3.2 has the clinical values for participants in the placebo therapy group. The placebo therapy CI participants have average values of 25.36±8.02 for CISS, 6.46±2.38 cm for NPC, and 21.36±9.04 Δ for PFV. Values for CISS, NPC, and PFV all showed statistically significant change ($p<0.001$). Table 3.3 has the results of unpaired t-tests for clinical measures between OBPT and OBVAT groups. Before therapy, none of the clinical measures have any statistical difference between groups. After therapy the between therapy PFV values have a difference with statistical significance of $p<0.001$, NPC have a statistical significance of $p<0.01$, and the CISS values exhibit a trend $p=0.1$.

3.2 Latency Results

Figures 3.1 to 3.3 show the combined movement results for latency with statistical significance shown. Table B1 shows the results from the Mixed ANOVA. Gender differences were not significant for any of the latency results. Movements with statistical significance were CON4, CON6, DIV6, DSCON4, DSDIV6, and SAC10. Table C1 shows

the unpaired t-test results. Unpaired t-tests with statistical significance were not identical to the results from the Mixed ANOVA. Tables D1 and D2 show the paired t-test results. Results with significance from both the Mixed ANOVA and paired t-tests were for CON4 before and after OBPT, and SAC10 before and after OBVAT.

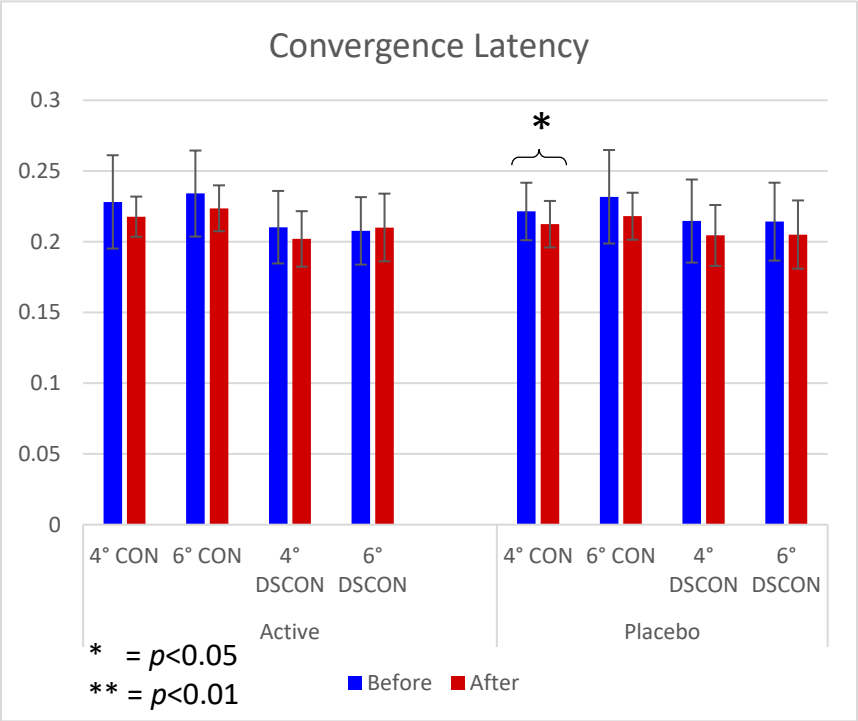

Figure 3.1 Bar plots showing the means and standard deviations of latency for convergence disparity and disappearing steps for both Active (OBVAT) and Placebo (OBPT) therapy groups.

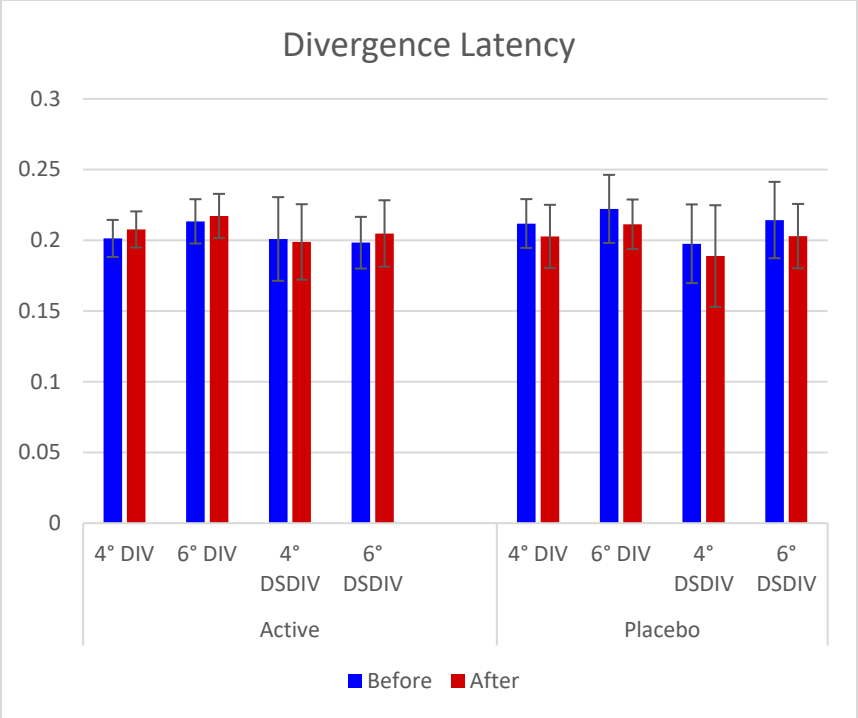

Figure 3.2 Bar plots showing the means and standard deviations of latency for divergence disparity and disappearing steps for both Active (OBVAT) and Placebo (OBPT) therapy groups.

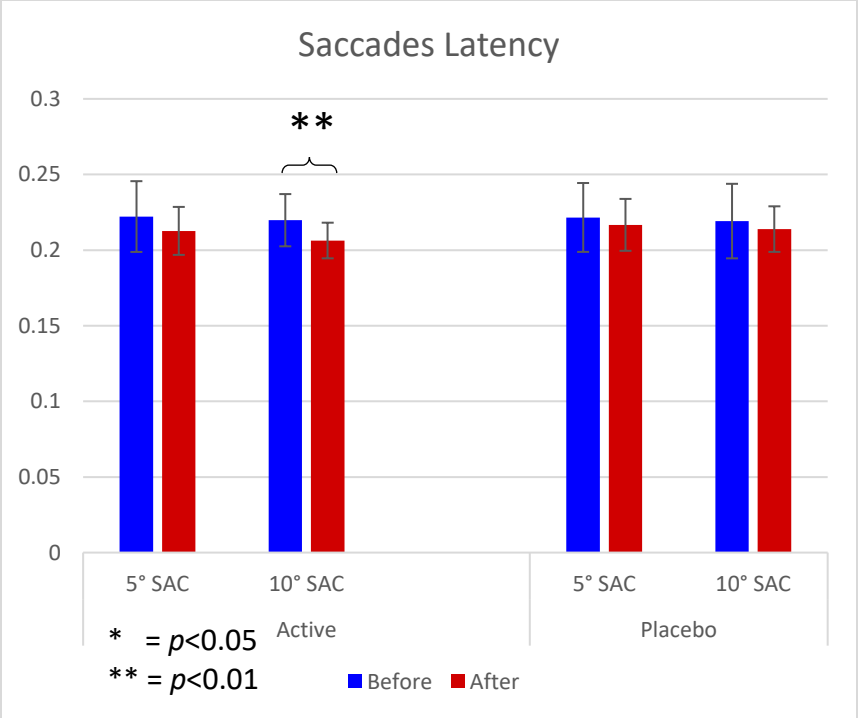

Figure 3.3 Bar plots showing the means and standard deviations of latency for saccades for both Active (OBVAT) and Placebo (OBPT) therapy groups.

3.3 Time to Peak Velocity Results

Figures 3.4 to 3.6 show the combined movement results for Time to Peak Velocity with statistical significance shown. Table B2 shows the results from the Mixed ANOVA. Gender differences were not significant for any of the time to peak velocity results. Movements with statistical significance were CON4, CON6, DSDIV4, SAC5, and SAC10. Table C2 shows the unpaired t-test results. Results with significance from both the Mixed ANOVA and unpaired t-tests were only DSDIV4 post therapy between OBPT and OBVAT. Tables D3 and D4 show the paired t-test results. Results with significance from both the Mixed ANOVA and paired t-tests were for CON4 and DSDIV4 before and after OBPT therapy, and CON4, CON6, SAC5, and SAC10 before and after OBVAT therapy.

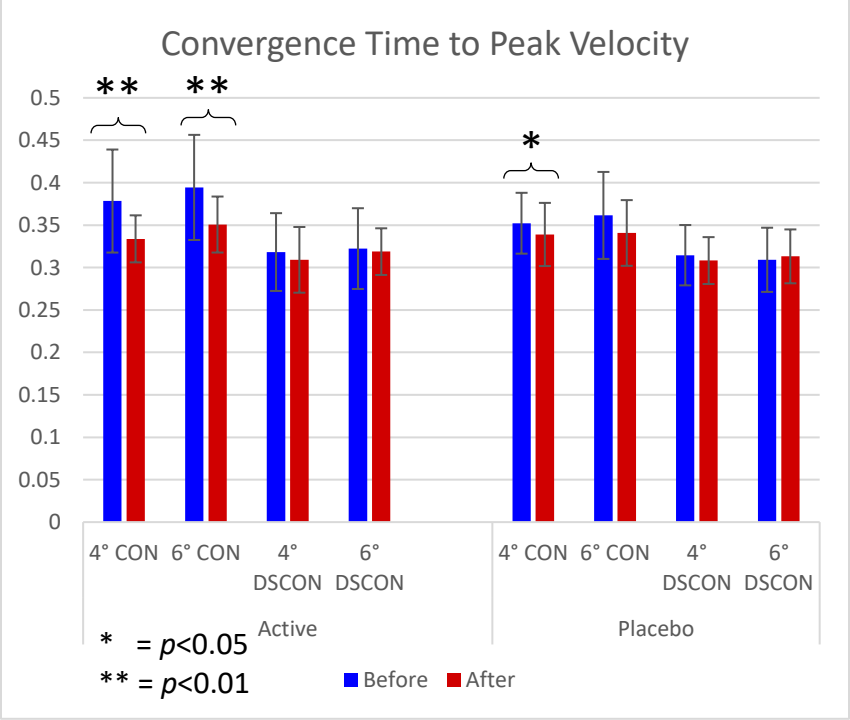

Figure 3.4 Bar plots showing the means and standard deviations of time to peak velocity for convergence disparity and disappearing steps for both Active (OBVAT) and Placebo (OBPT) therapy groups.

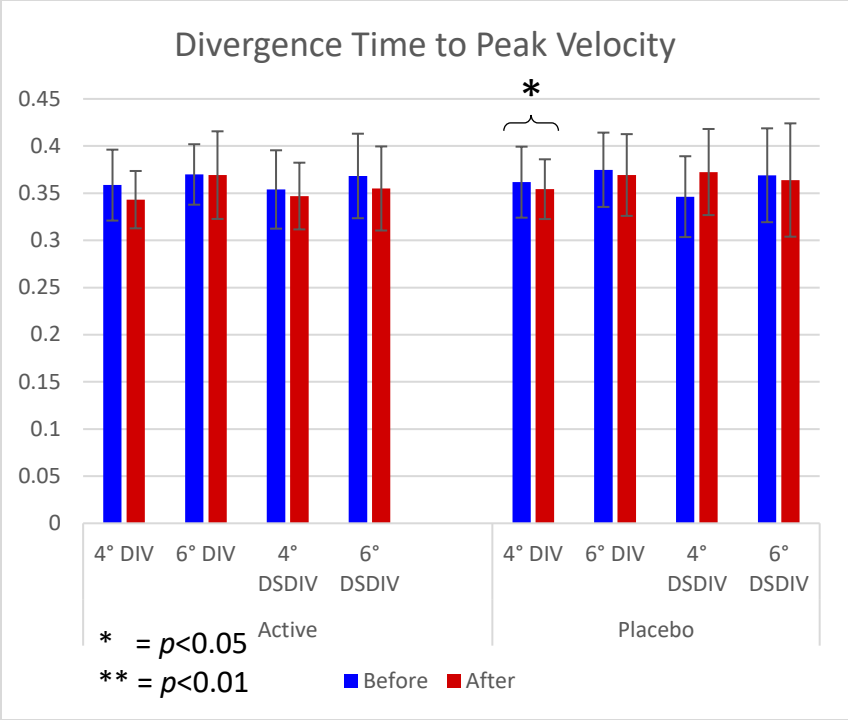

Figure 3.5 Bar plots showing the means and standard deviations of time to peak velocity for divergence disparity and disappearing steps for both Active (OBVAT) and Placebo (OBPT) therapy groups.

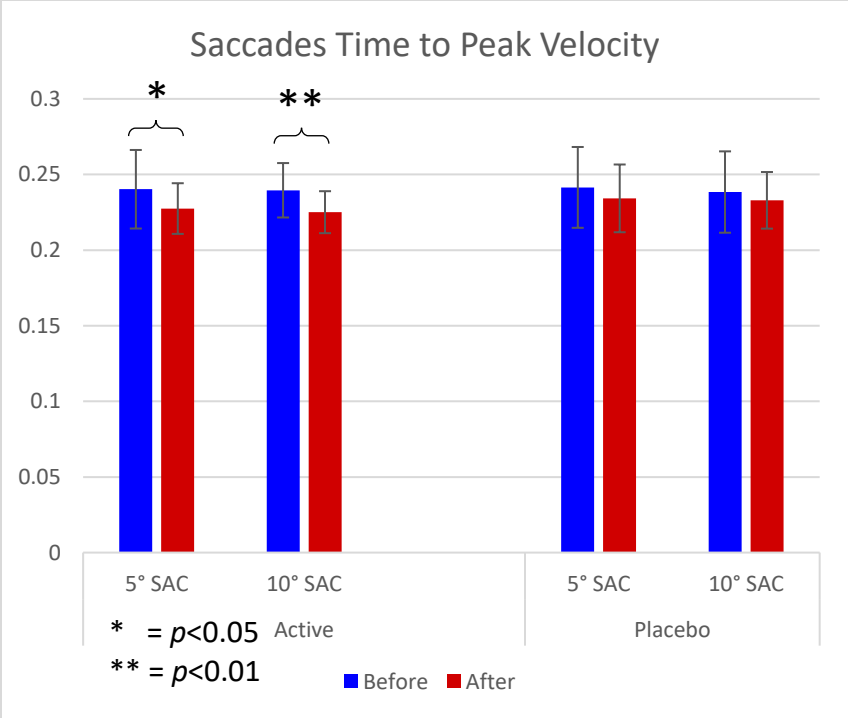

Figure 3.6 Bar plots showing the means and standard deviations of time to peak velocity for saccades for both Active (OBVAT) and Placebo (OBPT) therapy groups.

3.4 Peak Velocity Results

Figures 3.7 to 3.9 show the combined movement results for Peak Velocity with statistical significance shown. Table B3 shows the results from the Mixed ANOVA. Gender differences were not significant for any of the peak velocity results. Movements with statistical significance were CON4, CON6, DIV4, DIV6, and DSDIV4. Table C3 shows the unpaired t-test results. Unpaired t-tests with statistical significance were not identical to the results from the Mixed ANOVA. Tables D5 and D6 show the paired t-test results. Results with significance from both the Mixed ANOVA and paired t-tests were for CON4, DIV4, and DSDIV4 before and after OBPT therapy, and CON4, CON6, DIV4, and DIV6 before and after OBVAT therapy.

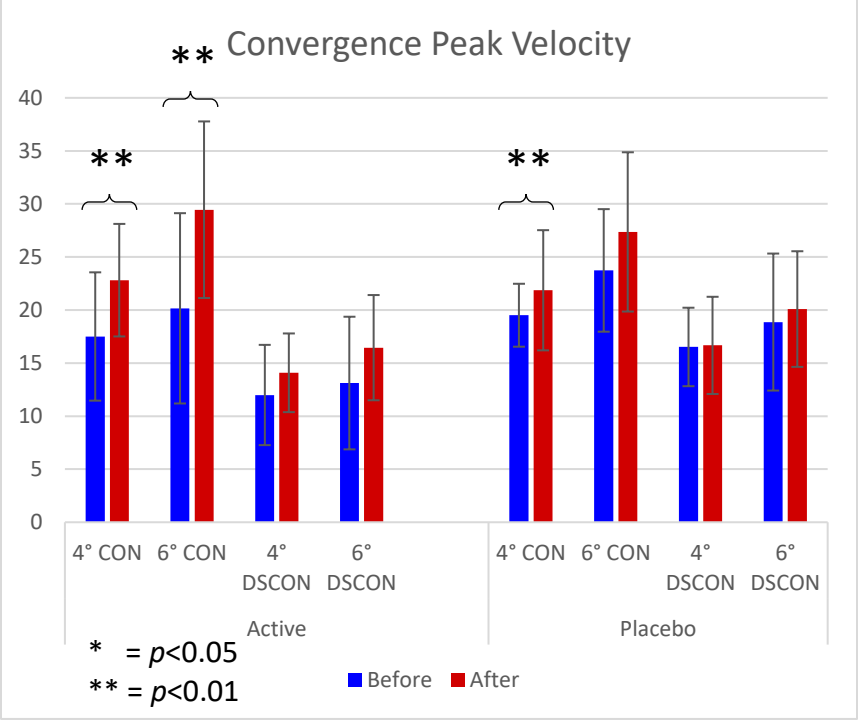

Figure 3.7 Bar plots showing the means and standard deviations of peak velocity for convergence disparity and disappearing steps for both Active (OBVAT) and Placebo (OBPT) therapy groups.

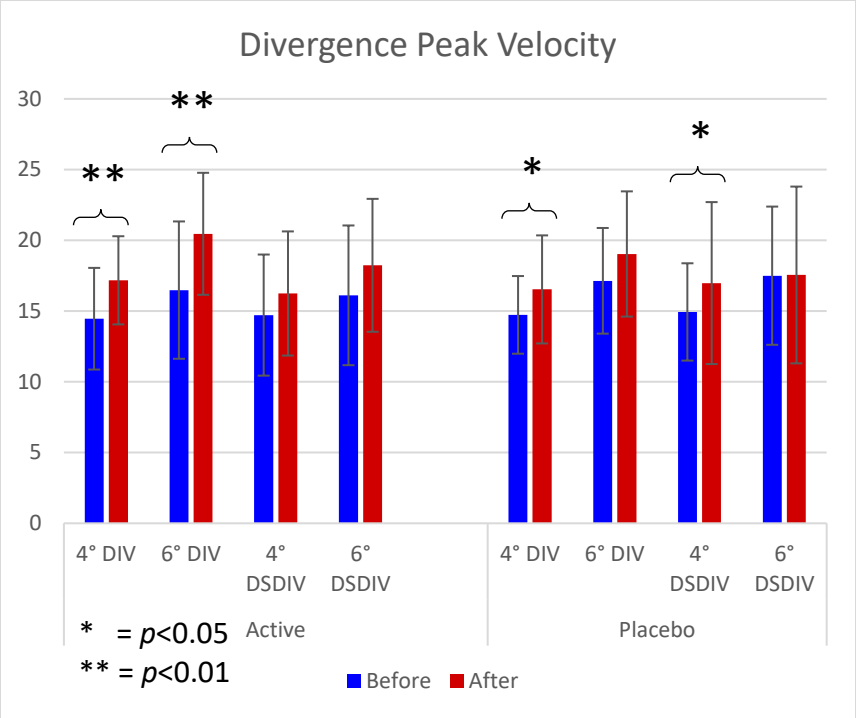

Figure 3.8 Bar plots showing the means and standard deviations of peak velocity for divergence disparity and disappearing steps for both Active (OBVAT) and Placebo (OBPT) therapy groups.

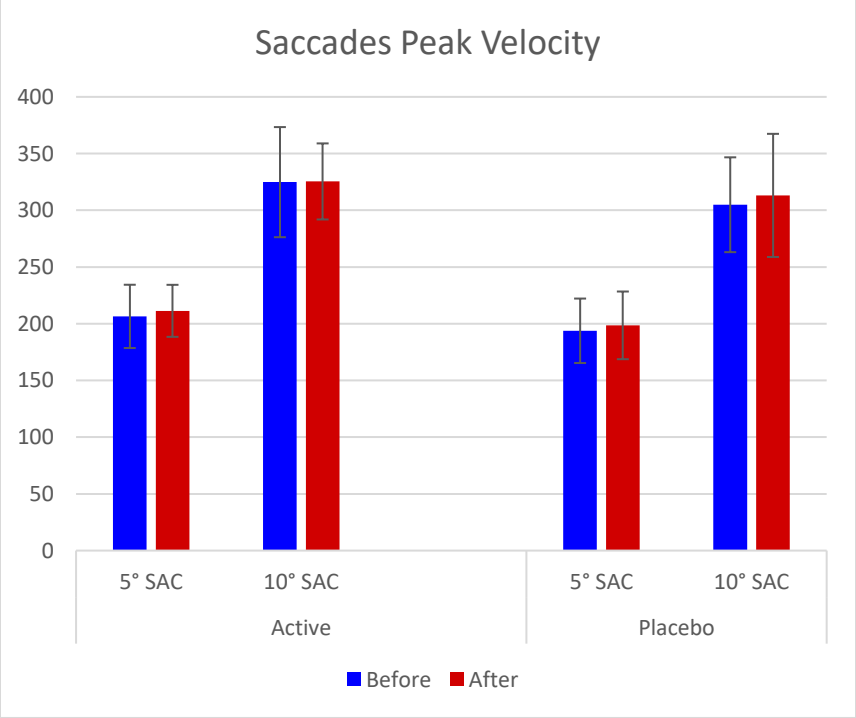

Figure 3.9 Bar plots showing the means and standard deviations of peak velocity for saccades for both Active (OBVAT) and Placebo (OBPT) therapy groups.

3.5 Final Amplitude Results

The target disappears before a final amplitude can be reach during disappearing steps. Thus, disappearing step results for final amplitude are not shown due to a lack of meaning. Figures 3.10 to 3.11 show the combined movement results for Final Amplitude with statistical significance shown. Table B4 shows the results from the Mixed ANOVA. There were no significant values from the Mixed ANOVA, thus there are no t-test values that showed significance with the Mixed ANOVA results.

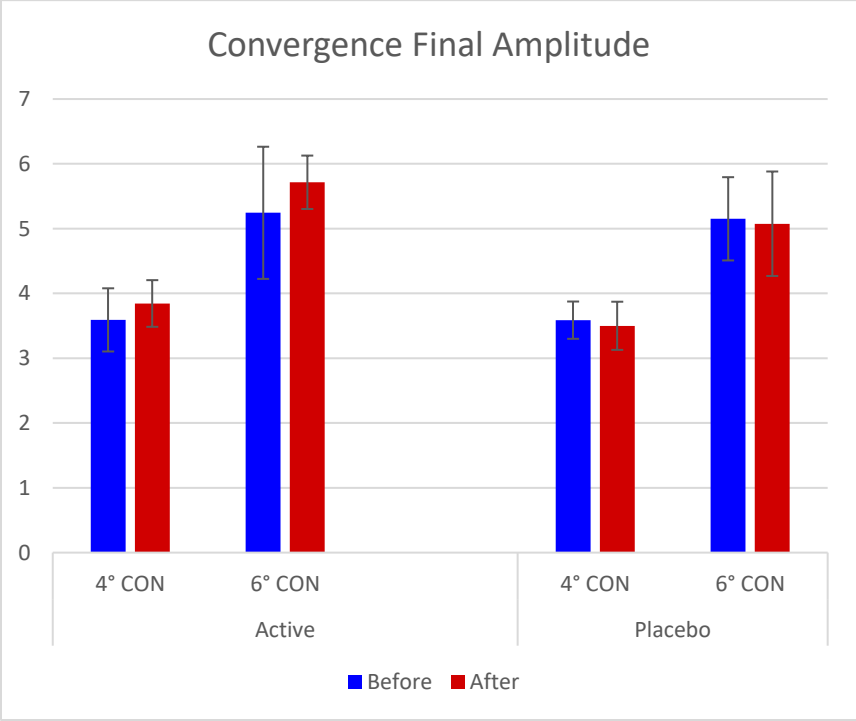

Figure 3.10 Bar plots showing the means and standard deviations of final amplitude for convergence disparity and disappearing steps for both Active (OBVAT) and Placebo (OBPT) therapy groups.

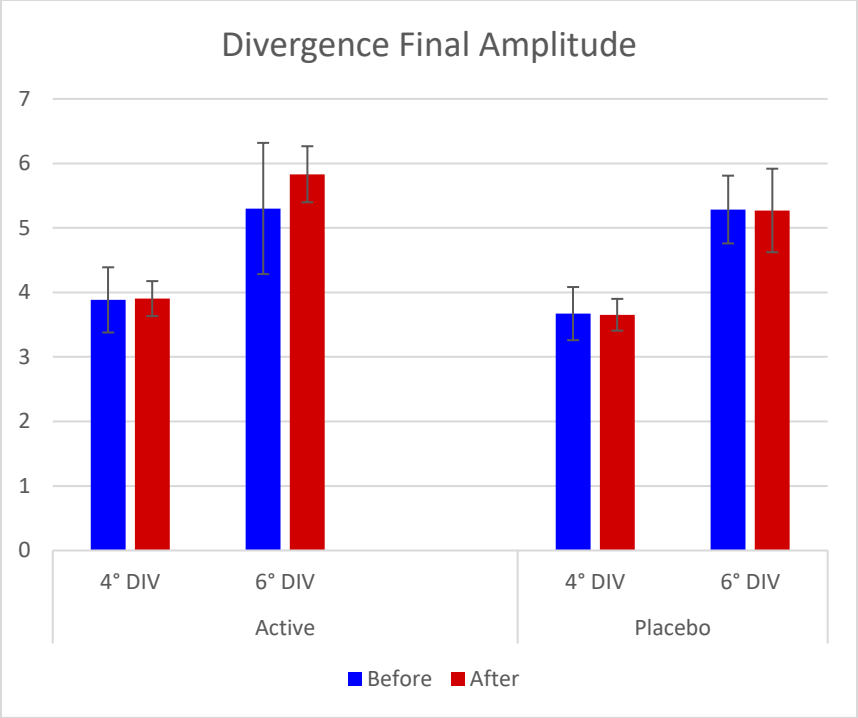

Figure 3.11 Bar plots showing the means and standard deviations of final amplitude for divergence disparity and disappearing steps for both Active (OBVAT) and Placebo (OBPT) therapy groups.

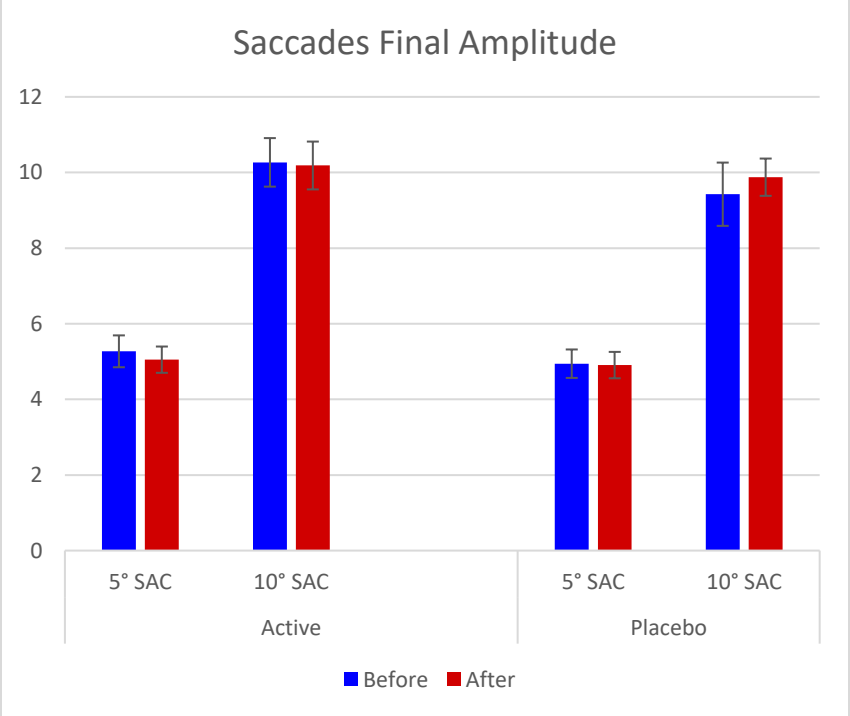

Figure 3.12 Bar plots showing the means and standard deviations of final amplitude for saccades for both Active (OBVAT) and Placebo (OBPT) therapy groups.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

4.1 Discussion

The clinical values of CISS, NPC, and PFV are statistically different after therapy regardless of therapy type. Further, although the CISS, NPC, and PFV have no statistical difference between the two groups (OBPT and OBVAT) before therapy, after therapy there is a statistical difference between both of the following clinical parameters: NPC and PFV. The improvement in clinical parameters supports that the participants improved after therapy, and OBVAT improved patient outcomes significantly greater than OBPT. These results agree with previous studies [42]. It can also be noted that average values for CISS, NPC, and PFV were well above the symptomatic cutoff values for both OBVAT and OBPT groups before therapy. After OBVAT the average CISS changed from 33.96±8.97 with a range of 21 to 57, to 21.64±7.00 with a range of 7 to 40, which is remarkably close to the 21 threshold for symptomatic CI diagnosis. Further, the average NPC and PFV values changed from 10.54±3.67 cm with a range of 6.5 cm to 21cm and 12.24±3.18Δ with a range of 6Δ to 18Δ to 4.54±1.60cm with a range of 2.5cm to 8cm and 34.44±11.66Δ with a range of 16Δ to 50Δ. Both of the average values for NPC and PFV changed from the symptomatic CI diagnosis threshold to non-symptomatic. The NPC improved to below 6cm and the PFV improved to above 15Δ. However, none of the average clinical measures (CISS, NPC, and PFV) changed to below the symptomatic CI threshold after therapy for OBPT. Clinical results were similar to other randomized clinical trials [42]. This is the first

properly powered randomized clinical trial to include eye movement metrics before and after vision therapy.

The Dual Mode Theory of disparity vergence has two components the preprogrammed FIC, and feedback controlled FSC [18]-[23]. The FIC is believed to be generated by the "velocity-encoding" burst cells near the oculomotor nucleus in the midbrain. The FSC mimics the "position-encoding" tonic cells located in the midbrain. The burst and tonics cells are distinct. The peak velocity metric is used to assess the FIC, and the final amplitude metric is used to assess the FSC.

The final amplitude results have no statistically significant difference before or after any therapy or between therapy groups. The lack of change in final amplitude suggests that the FSC is not as strongly affected by therapy as the FIC. The saccadic movements were included as a control measure since CI subjects have disfunction in vergence movements, not saccades. The lack of statically significant change in the final amplitude of the saccades, as well as the relative accuracy and precision of these movements to the expected outcomes (5 and 10 degrees of change) demonstrates that eye movements were properly calibrated. It should be noted that if a participant is unable to complete an eye movement, it is not analyzed. The final amplitude results show a general trend that subjects generally have a binary response, either the participants make a successful eye movement to achieve fusion of the image, or they fail catastrophically. It is extremely rare for a participant to have an eye movement that fails to achieve fusion of the image and stabilizes just above or below the correct fusion angle. If a participant is unable to achieve fusion, they tend to lose fusion.

The peak velocity results showed general trends of increased peak velocity after therapy. The OBVAT group has statistically significant ($p<0.01$) changes after therapy for

4° convergence and divergence, and 6° convergence and divergence steps. The OBPT group had statistically significant changes after therapy for 4° convergence ($p<0.01$), and 4° divergence and disappearing divergence ($p<0.05$) steps. These results show the peak velocity of participants statistically improved after therapy. The change in peak velocity confirms the FIC of the Dual Mode Theory of disparity vergence is changing due to both therapies. However, OBVAT showed more change than OBPT, both in the number of movements with statistical difference, and the degree of statistical significance for those movements. These results agree with the clinical measures which also showed a statistically significant change in both therapy groups, but with a larger change in the OBVAT over OBPT group.

The latency results showed general trends of decreasing after therapy –faster reaction time. The 4° convergence for OBPT and 10° saccade for OBVAT were the only movements with statically significant changes after therapy. In general, these results were similar for OBPT and OBVAT. The time to peak velocity showed similar trends to latency in which it generally decreased after therapy. The 4° and 6° convergence and 5° and 10° saccades for the OBVAT group changed significantly after therapy. The 4° convergence and divergence steps for the OBPT group changed significantly after therapy. These results show decreases in both therapy groups, with the OBVAT group showing more change than OBPT, both in the number of movements with statistical difference, and the degree of statistical significance for those movements. Generally, latency and time to peak velocity are correlated values. The latency can be viewed as the reaction time. The time to peak velocity can be viewed as a measure of the acceleration of the eye. Thus, both therapy

groups improve the reaction time to a relatively similar degree. However, the OBVAT therapy group improves the acceleration of the eye more significantly than the OBPT.

The latency and time to peak velocity results agree with previous studies showing improvements in saccades due to vergence rehabilitation [51],[52]. Other studies have gone as far as to suggest saccade-vergence interactions in human which could be the cause for improvements in saccades from vergence therapy [53]. Further it has been shown that large amounts of visual stimuli such as in videogames and training can speed up reaction time [54].

The results objective eye movement measures were generally the same for convergence and divergence movements. The latency, time to peak, and final amplitude results all were about the same values and showed the same trends when comparing the same type of movements (CON4 to DIV4, DSCON6 to DSDIV6, etc.). Generally, the peak velocity for convergence movements was higher than divergence movements, but the changes after therapy were approximately the same. Behavioral plots are provided in APPENDIX E for reference.

4.1 Conclusions and Future Work

This study showed that OBVAT leads to statistically significant improvements in the disparity vergence oculomotor system. Further, these improvements are greater for OBVAT compared to OBPT. These improvements can be seen both in clinical measures, and in objective measures of eye movements. The results from the clinical and objective measures agree with one another. The eye movement measures of final amplitude and peak velocity show that the different components of the Dual-Mode Model are trained during

therapy. The FIC is trained, while the final amplitude does not show a statistically significant change. This study looks at CI participants. These results can be used to compare against similar results to binocularly normal controls.

A limitation of the current study methodology is that it does not take into account the eye movements that fail. Different measures could be developed which account for and measure these failures. For instance, a percentage of successful movements could be measured to show if participants have more successful movements, and thus less failures, after therapy. It could also be possible to develop a method of averaging similar movement types together, smoothing the results, and then taking movement measures from the averaged eye movement wave. This metric would not give accurate absolute measures of the eye movements, but would give relative measures of the eye movements which could be compared before and after therapy. This metric would have the benefit of accounting for failed movements, as well as, the scattering and imprecision of similar movements. Increased precision and reliability of movements would cause sharper averaged eye movements.

An asymmetry analysis between the left and right eye movement response would also yield insight into the differences between the dominance of one eye compared to another. Prior pilot studies support that CI eye movements are more asymmetrical compared to binocularly normal controls and that asymmetry improves post therapy [55],[56].

Overall the results of this study support the effectiveness of office-based vergence and accommodation therapy for people with CI. Participant reported symptoms, clinical

measures, and objective eye movement measures all improve in people with CI who undergo OBVAT.

APPENDIX A

CONVERGENCE INSUFFICIENCY SYMPTOM SURVEY (CISS)

Convergence Insufficiency - Symptom Questionnaire V-15

Name _____ DATE __/__/__

Subject instructions: Please answer the following questions about how your eyes feel when reading or doing close work. Choose your response from the card that I have just handed you.

		Never	Infrequently	Sometimes	Fairly often	Always
1.	Do your eyes feel tired when reading or doing close work?					
2.	Do your eyes feel uncomfortable when reading or doing close work?					
3.	Do you have headaches when reading or doing close work?					
4.	Do you feel sleepy when reading or doing close work?					
5.	Do you lose concentration when reading or doing close work?					
6.	Do you have trouble remembering what you have read?					
7.	Do you have double vision when reading or doing close work?					
8.	Do you see the words move, jump, swim or appear to float on the page when reading or doing close work?					
9.	Do you feel like you read slowly?					
10.	Do your eyes ever hurt when reading or doing close work?					
11.	Do your eyes ever feel sore when reading or doing close work?					
12.	Do you feel a "pulling" feeling around your eyes when reading or doing close work?					
13.	Do you notice the words blurring or coming in and out of focus when reading or doing close work?					
14.	Do you lose your place while reading or doing close work?					
15.	Do you have to re-read the same line of words when reading?					
	TOTAL Xs in each column	x 0	x 1	x 2	x 3	x 4

Score _____

Figure A1 Convergence Insufficiency Symptom Survey (CISS).

APPENDIX B

MIXED ANOVA

Table B1 A table of statistical results from a Mixed ANOVA, showing the factor, error df, and significance between-factor (before vs after therapy), between-sex (M vs F), and between-therapy (OBPT vs OBVAT) for each movement's Latency. The tests with statistical significance are highlighted in green.

Latency				
		F	Error df	Sig
CON4	Factor	5.675b	44	0.0216
	Sex	.196b	44	0.660134
	Therapy	.030b	44	0.864347
CON6	Factor	9.394b	40	0.003889
	Sex	2.426b	40	0.127232
	Therapy	.211b	40	0.648386
DIV4	Factor	.494b	41	0.486177
	Sex	1.932b	41	0.172
	Therapy	3.024b	41	0.089549
DIV6	Factor	3.864b	38	0.056669
	Sex	2.359b	38	0.132828
	Therapy	4.308b	38	0.044747
DSCON4	Factor	6.632b	31	0.015011
	Sex	3.633b	31	0.06597
	Therapy	.356b	31	0.555168
DSCON6	Factor	1.901b	29	0.17846
	Sex	.812b	29	0.375038
	Therapy	.190b	29	0.666321
DSDIV4	Factor	1.229b	39	0.274379
	Sex	.905b	39	0.347306
	Therapy	.193b	39	0.663226
DSDIV6	Factor	.095b	34	0.760193
	Sex	.393b	34	0.535048
	Therapy	4.385b	34	0.043784
SAC5	Factor	3.252b	47	0.077749
	Sex	.010b	47	0.922647
	Therapy	.587b	47	0.447248
SAC10	Factor	12.509b	47	0.000923
	Sex	.972b	47	0.329183
	Therapy	2.614b	47	0.112629

Table B2 A table of statistical results from a Mixed ANOVA, showing the factor, error df, and significance between-factor (before vs after therapy), between-sex (M vs F), and between-therapy (OBPT vs OBVAT) for each movement's Time to Peak Velocity. The tests with statistical significance are highlighted in green.

Time to Peak Velocity				
		F	Error df	Sig
CON4	Factor	11.581b	44	0.00143
	Sex	.195b	44	0.660785
	Therapy	2.976b	44	0.091535
CON6	Factor	15.834b	41	0.000275
	Sex	3.530b	41	0.067381
	Therapy	1.552b	41	0.219863
DIV4	Factor	1.516b	41	0.225287
	Sex	.442b	41	0.509906
	Therapy	.550b	41	0.462699
DIV6	Factor	.508b	35	0.480717
	Sex	.031b	35	0.862325
	Therapy	.161b	35	0.690729
DSCON4	Factor	1.543b	31	0.223418
	Sex	1.408b	31	0.244422
	Therapy	.002b	31	0.965297
DSCON6	Factor	1.976b	28	0.170809
	Sex	3.488b	28	0.072303
	Therapy	.001b	28	0.972101
DSDIV4	Factor	.951b	40	0.335244
	Sex	.018b	40	0.894409
	Therapy	6.599b	40	0.014038
DSDIV6	Factor	.206b	37	0.652667
	Sex	.010b	37	0.921024
	Therapy	2.909b	37	0.096461
SAC5	Factor	5.946b	47	0.018584
	Sex	.141b	47	0.709145
	Therapy	.635b	47	0.429527
SAC10	Factor	13.881b	47	0.000522
	Sex	1.718b	47	0.196363
	Therapy	2.619b	47	0.11225

Table B3 A table of statistical results from a Mixed ANOVA, showing the factor, error df, and significance between-factor (before vs after therapy), between-sex (M vs F), and between-therapy (OBPT vs OBVAT) for each movement's Peak Velocity. The tests with statistical significance are highlighted in green.

Peak Velocity				
		F	Error df	Sig
CON4	Factor	9.402b	44	0.003699
	Sex	.636b	44	0.429402
	Therapy	1.679b	44	0.201775
CON6	Factor	6.071b	41	0.018027
	Sex	1.810b	41	0.185843
	Therapy	4.129b	41	0.048668
DIV4	Factor	10.371b	42	0.002472
	Sex	.000b	42	0.98866
	Therapy	.280b	42	0.599457
DIV6	Factor	5.311b	38	0.026748
	Sex	.840b	38	0.365075
	Therapy	2.782b	38	0.103573
DSCON4	Factor	.146b	30	0.704808
	Sex	1.543b	30	0.223779
	Therapy	.562b	30	0.459258
DSCON6	Factor	2.112b	28	0.157262
	Sex	.018b	28	0.892817
	Therapy	.028b	28	0.868184
DSDIV4	Factor	6.138b	39	0.017673
	Sex	.230b	39	0.634299
	Therapy	.631b	39	0.431823
DSDIV6	Factor	.838b	35	0.366231
	Sex	.151b	35	0.69968
	Therapy	1.451b	35	0.236491
SAC5	Factor	3.901b	47	0.054159
	Sex	2.521b	47	0.119073
	Therapy	.032b	47	0.858595
SAC10	Factor	1.758b	47	0.191273
	Sex	1.305b	47	0.259031
	Therapy	.581b	47	0.449561

Table B4 A table of statistical results from a Mixed ANOVA, showing the factor, error df, and significance between-factor (before vs after therapy), between-sex (M vs F), and between-therapy (OBPT vs OBVAT) for each movement's Final Amplitude. The tests with statistical significance are highlighted in green.

Final Amplitude				
		F	Error df	Sig
CON4	Factor	1.525b	43	0.223642
	Sex	.174b	43	0.678233
	Therapy	3.301b	43	0.07621
CON6	Factor	1.205b	40	0.2788
	Sex	.048b	40	0.827487
	Therapy	1.301b	40	0.260891
DIV4	Factor	.554b	42	0.460906
	Sex	.830b	42	0.367603
	Therapy	.013b	42	0.911338
DIV6	Factor	2.113b	38	0.154266
	Sex	.547b	38	0.463897
	Therapy	1.989b	38	0.166532
DSCON4	Factor	1.502b	30	0.22993
	Sex	.092b	30	0.764235
	Therapy	1.705b	30	0.201597
DSCON6	Factor	.016b	28	0.901609
	Sex	.084b	28	0.77411
	Therapy	.073b	28	0.788995
DSDIV4	Factor	1.575b	29	0.219491
	Sex	.119b	29	0.732148
	Therapy	.158b	29	0.693625
DSDIV6	Factor	.426b	37	0.517828
	Sex	.017b	37	0.898097
	Therapy	.233b	37	0.632427
SAC5	Factor	1.217b	47	0.275639
	Sex	.000b	47	0.984925
	Therapy	1.265b	47	0.266445
SAC10	Factor	.448b	47	0.506726
	Sex	.173b	47	0.679634
	Therapy	3.678b	47	0.061238

APPENDIX C

UNPAIRED T-TESTS

Table C1 A table of statistical results from an Unpaired T-Test between therapy groups (OBPT vs OBVAT) performed for all movements, before and after therapy for each movement's Latency. The tests with statistical significance are highlighted in green.

Latency										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
CON4PRE	Equal variances assumed	1.020	.318	-.823	45	.415	-.00676	.00821	-.02329	.00977
	Equal variances not assumed			-.831	38.524	.411	-.00676	.00813	-.02321	.00969
CON4POST	Equal variances assumed	.938	.338	-1.179	47	.244	-.00528	.00448	-.01428	.00372
	Equal variances not assumed			-1.176	45.426	.246	-.00528	.00449	-.01432	.00376
CON6PRE	Equal variances assumed	.229	.635	-.229	41	.820	-.00227	.00993	-.02233	.01778
	Equal variances not assumed			-.229	40.951	.820	-.00227	.00991	-.02229	.01774
CON6POST	Equal variances assumed	.077	.782	-1.172	47	.247	-.00561	.00479	-.01525	.00402
	Equal variances not assumed			-1.171	46.790	.247	-.00561	.00479	-.01526	.00403
DIV4PRE	Equal variances assumed	3.260	.078	2.248	43	.030	.01053	.00469	.00108	.01998
	Equal variances not assumed			2.262	40.930	.029	.01053	.00466	.00113	.01994
DIV4POST	Equal variances assumed	3.387	.072	-.922	46	.361	-.00489	.00531	-.01557	.00579
	Equal variances not assumed			-.903	34.389	.373	-.00489	.00542	-.01591	.00612
DIV6PRE	Equal variances assumed	4.596	.038	1.357	40	.182	.00881	.00649	-.00431	.02193
	Equal variances not assumed			1.384	36.445	.175	.00881	.00637	-.00409	.02171
DIV6POST	Equal variances assumed	.145	.705	-1.192	44	.240	-.00595	.00499	-.01601	.00411
	Equal variances not assumed			-1.186	42.158	.242	-.00595	.00502	-.01608	.00418
DSCON4PRE	Equal variances assumed	.022	.884	.460	34	.649	.00436	.00948	-.01491	.02362

	Equal variances not assumed			.448	27.452	.657	.00436	.00972	-.01557	.02428
DSCON4POST	Equal variances assumed	.597	.444	.375	40	.710	.00245	.00654	-.01077	.01567
	Equal variances not assumed			.369	34.616	.714	.00245	.00664	-.01103	.01593
DSCON6PRE	Equal variances assumed	.009	.924	.707	32	.484	.00652	.00921	-.01225	.02528
	Equal variances not assumed			.681	22.504	.503	.00652	.00957	-.01331	.02635
DSCON6POST	Equal variances assumed	.174	.679	-.635	38	.529	-.00500	.00788	-.02096	.01095
	Equal variances not assumed			-.633	34.302	.531	-.00500	.00790	-.02105	.01105
DSDIV4PRE	Equal variances assumed	.130	.720	-.371	41	.713	-.00336	.00906	-.02167	.01494
	Equal variances not assumed			-.374	39.653	.711	-.00336	.00900	-.02157	.01484
DSDIV4POST	Equal variances assumed	2.214	.144	-1.042	43	.303	-.00995	.00956	-.02923	.00932
	Equal variances not assumed			-1.007	34.074	.321	-.00995	.00988	-.03004	.01013
DSDIV6PRE	Equal variances assumed	1.183	.284	2.147	37	.038	.01602	.00746	.00090	.03113
	Equal variances not assumed			2.042	26.635	.051	.01602	.00784	-.00008	.03212
DSDIV6POST	Equal variances assumed	.027	.870	-.258	42	.797	-.00187	.00722	-.01643	.01270
	Equal variances not assumed			-.259	39.389	.797	-.00187	.00719	-.01641	.01268
SAC5PRE	Equal variances assumed	.083	.774	-.088	48	.930	-.00059	.00667	-.01399	.01282
	Equal variances not assumed			-.088	47.964	.930	-.00059	.00667	-.01399	.01282
SAC5POST	Equal variances assumed	.039	.845	.837	48	.406	.00400	.00477	-.00560	.01359
	Equal variances not assumed			.837	47.701	.406	.00400	.00477	-.00560	.01359
SAC10PRE	Equal variances assumed	2.873	.097	-.094	48	.925	-.00058	.00614	-.01293	.01177
	Equal variances not assumed			-.094	43.000	.925	-.00058	.00614	-.01297	.01181
SAC10POST	Equal variances assumed	1.299	.260	1.934	48	.059	.00755	.00391	-.00030	.01541
	Equal variances not assumed			1.934	45.382	.059	.00755	.00391	-.00031	.01542

Table C2 A table of statistical results from an Unpaired T-Test between therapy groups (OBPT vs OBVAT) performed for all movements, before and after therapy for each movement's Time to Peak Velocity. The tests with statistical significance are highlighted in green.

Time to Peak Velocity										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
CON4PRE	Equal variances assumed	3.866	.055	-1.750	45	.087	-.02615	.01495	-.05626	.00395
	Equal variances not assumed			-1.768	37.606	.085	-.02615	.01479	-.05611	.00380
CON4POST	Equal variances assumed	2.306	.135	.549	48	.586	.00519	.00947	-.01385	.02424
	Equal variances not assumed			.549	44.361	.586	.00519	.00947	-.01389	.02428
CON6PRE	Equal variances assumed	.524	.473	-1.880	42	.067	-.03298	.01754	-.06839	.00242
	Equal variances not assumed			-1.880	40.582	.067	-.03298	.01754	-.06842	.00246
CON6POST	Equal variances assumed	.338	.564	-.948	47	.348	-.00993	.01048	-.03101	.01115
	Equal variances not assumed			-.945	45.184	.350	-.00993	.01051	-.03111	.01124
DIV4PRE	Equal variances assumed	.001	.976	.269	42	.789	.00312	.01161	-.02031	.02655
	Equal variances not assumed			.269	42.000	.789	.00312	.01161	-.02031	.02655
DIV4POST	Equal variances assumed	.339	.563	1.227	47	.226	.01111	.00906	-.00711	.02933
	Equal variances not assumed			1.226	46.673	.226	.01111	.00906	-.00713	.02935
DIV6PRE	Equal variances assumed	1.543	.222	.431	39	.669	.00497	.01154	-.01836	.02830
	Equal variances not assumed			.433	38.103	.667	.00497	.01148	-.01826	.02820
DIV6POST	Equal variances assumed	.173	.680	.007	43	.995	.00009	.01376	-.02766	.02785
	Equal variances not assumed			.007	42.786	.995	.00009	.01370	-.02754	.02773
DSCON4PRE	Equal variances assumed	.089	.767	-.250	34	.804	-.00371	.01482	-.03383	.02641
	Equal variances not assumed			-.264	32.319	.794	-.00371	.01405	-.03230	.02489
DSCON4POST	Equal variances assumed	1.201	.280	-.076	40	.939	-.00084	.01099	-.02306	.02137
	Equal variances not assumed			-.080	39.950	.937	-.00084	.01049	-.02204	.02036

DSCON6PRE	Equal variances assumed	.056	.814	-.821	32	.418	-.01318	.01605	-.04587	.01951
	Equal variances not assumed			-.865	29.602	.394	-.01318	.01525	-.04434	.01797
DSCON6POST	Equal variances assumed	.512	.479	-.559	36	.580	-.00557	.00997	-.02579	.01465
	Equal variances not assumed			-.541	26.695	.593	-.00557	.01031	-.02674	.01559
DSDIV4PRE	Equal variances assumed	.152	.699	-.583	42	.563	-.00762	.01306	-.03398	.01874
	Equal variances not assumed			-.581	40.025	.564	-.00762	.01311	-.03411	.01887
DSDIV4POST	Equal variances assumed	1.412	.241	2.082	44	.043	.02546	.01223	.00082	.05010
	Equal variances not assumed			2.036	37.251	.049	.02546	.01250	.00013	.05079
DSDIV6PRE	Equal variances assumed	.256	.616	.048	39	.962	.00073	.01518	-.02998	.03143
	Equal variances not assumed			.047	34.498	.963	.00073	.01539	-.03054	.03199
DSDIV6POST	Equal variances assumed	1.627	.209	.561	43	.578	.00896	.01597	-.02325	.04117
	Equal variances not assumed			.542	34.047	.591	.00896	.01652	-.02461	.04252
SAC5PRE	Equal variances assumed	.557	.459	.161	48	.873	.00123	.00761	-.01407	.01652
	Equal variances not assumed			.161	47.961	.873	.00123	.00761	-.01407	.01652
SAC5POST	Equal variances assumed	1.490	.228	1.180	48	.244	.00674	.00571	-.00474	.01821
	Equal variances not assumed			1.180	44.451	.244	.00674	.00571	-.00477	.01824
SAC10PRE	Equal variances assumed	2.878	.096	-.176	48	.861	-.00116	.00661	-.01444	.01212
	Equal variances not assumed			-.176	41.906	.861	-.00116	.00661	-.01449	.01217
SAC10POST	Equal variances assumed	1.412	.241	1.648	48	.106	.00784	.00476	-.00173	.01740
	Equal variances not assumed			1.648	44.262	.106	.00784	.00476	-.00175	.01742

Table C3 A table of statistical results from an Unpaired T-Test between therapy groups (OBPT vs OBVAT) performed for all movements, before and after therapy for each movement's Peak Velocity. The tests with statistical significance are highlighted in green.

Peak Velocity										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
CON4PRE	Equal variances assumed	10.638	.002	1.402	45	.168	2.00453	1.42951	-.87466	4.88372
	Equal variances not assumed			1.421	33.785	.164	2.00453	1.41062	-.86287	4.87194
CON4POST	Equal variances assumed	.090	.766	-.601	48	.551	-.95158	1.58360	-4.13563	2.23246
	Equal variances not assumed			-.601	47.794	.551	-.95158	1.58360	-4.13598	2.23282
CON6PRE	Equal variances assumed	3.663	.062	1.536	42	.132	3.57510	2.32756	-1.12211	8.27231
	Equal variances not assumed			1.536	35.862	.133	3.57510	2.32756	-1.14604	8.29624
CON6POST	Equal variances assumed	.650	.424	-.904	47	.371	-2.09189	2.31472	-6.74851	2.56473
	Equal variances not assumed			-.906	46.829	.370	-2.09189	2.30981	-6.73907	2.55529
DIV4PRE	Equal variances assumed	1.297	.261	.280	43	.781	.27257	.97239	-1.68845	2.23359
	Equal variances not assumed			.279	39.279	.782	.27257	.97825	-1.70567	2.25081
DIV4POST	Equal variances assumed	.909	.345	-.634	47	.529	-.64344	1.01477	-2.68489	1.39802
	Equal variances not assumed			-.631	44.386	.531	-.64344	1.01905	-2.69669	1.40982
DIV6PRE	Equal variances assumed	2.024	.163	.482	40	.632	.65724	1.36256	-2.09659	3.41108
	Equal variances not assumed			.476	35.571	.637	.65724	1.37986	-2.14242	3.45691
DIV6POST	Equal variances assumed	.021	.886	-1.082	44	.285	-1.42624	1.31799	-4.08248	1.23000
	Equal variances not assumed			-1.081	43.405	.286	-1.42624	1.31964	-4.08683	1.23435
DSCON4PRE	Equal variances assumed	.210	.649	3.031	35	.005	4.52789	1.49376	1.49540	7.56037
	Equal variances not assumed			3.170	34.115	.003	4.52789	1.42853	1.62513	7.43065
DSCON4POST	Equal variances assumed	1.397	.245	1.912	38	.063	2.58393	1.35108	-.15119	5.31906
	Equal variances not assumed			1.828	27.309	.078	2.58393	1.41323	-.31425	5.48211
DSCON6PRE	Equal variances assumed	.015	.903	2.495	31	.018	5.74744	2.30348	1.04947	10.44542

	Equal variances not assumed			2.479	27.465	.020	5.74744	2.31885	.99331	10.50158
DSCON6POST	Equal variances assumed	.324	.573	2.143	38	.039	3.63786	1.69755	.20135	7.07438
	Equal variances not assumed			2.110	32.497	.043	3.63786	1.72451	.12726	7.14846
DSDIV4PRE	Equal variances assumed	.552	.462	.181	41	.857	.22387	1.23644	-2.27316	2.72090
	Equal variances not assumed			.186	40.972	.854	.22387	1.20593	-2.21161	2.65935
DSDIV4POST	Equal variances assumed	.230	.634	.482	44	.632	.73592	1.52601	-2.33955	3.81140
	Equal variances not assumed			.471	36.999	.640	.73592	1.56217	-2.42934	3.90119
DSDIV6PRE	Equal variances assumed	.026	.872	.875	39	.387	1.38788	1.58607	-1.82026	4.59601
	Equal variances not assumed			.876	36.749	.387	1.38788	1.58513	-1.82464	4.60039
DSDIV6POST	Equal variances assumed	1.923	.173	-.399	41	.692	-.68242	1.71000	-4.13583	2.77099
	Equal variances not assumed			-.386	32.477	.702	-.68242	1.76868	-4.28302	2.91818
SAC5PRE	Equal variances assumed	.003	.954	-1.563	48	.125	-12.70565	8.12723	-29.04654	3.63525
	Equal variances not assumed			-1.563	47.983	.125	-12.70565	8.12723	-29.04669	3.63540
SAC5POST	Equal variances assumed	2.248	.140	-1.666	48	.102	-12.79746	7.68210	-28.24335	2.64843
	Equal variances not assumed			-1.666	45.021	.103	-12.79746	7.68210	-28.26980	2.67487
SAC10PRE	Equal variances assumed	.585	.448	-1.524	48	.134	-19.92773	13.07412	-46.21501	6.35955
	Equal variances not assumed			-1.524	46.966	.134	-19.92773	13.07412	-46.22998	6.37452
SAC10POST	Equal variances assumed	11.750	.001	-.945	48	.349	-12.30740	13.02432	-38.49456	13.87976
	Equal variances not assumed			-.945	39.982	.350	-12.30740	13.02432	-38.63090	14.01611

Table C4 A table of statistical results from an Unpaired T-Test between therapy groups (OBPT vs OBVAT) performed for all movements, before and after therapy for each movement's Final Amplitude. The tests with statistical significance are highlighted in green.

Final Amplitude										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
CON4PRE	Equal variances assumed	6.924	.012	-.036	44	.972	-.00431	.12064	-.24743	.23882
	Equal variances not assumed			-.036	35.665	.972	-.00431	.12064	-.24905	.24044
CON4POST	Equal variances assumed	.138	.712	-3.228	47	.002	-.34448	.10673	-.55919	-.12978
	Equal variances not assumed			-3.226	46.739	.002	-.34448	.10680	-.55937	-.12960
CON6PRE	Equal variances assumed	4.473	.041	-.349	41	.729	-.09249	.26495	-.62757	.44260
	Equal variances not assumed			-.345	33.432	.732	-.09249	.26770	-.63686	.45188
CON6POST	Equal variances assumed	5.851	.019	-3.444	47	.001	-.63955	.18569	-1.01311	-.26598
	Equal variances not assumed			-3.402	33.926	.002	-.63955	.18798	-1.02159	-.25750
DIV4PRE	Equal variances assumed	1.236	.272	-1.518	43	.136	-.21301	.14030	-.49595	.06993
	Equal variances not assumed			-1.511	40.532	.138	-.21301	.14095	-.49776	.07174
DIV4POST	Equal variances assumed	.178	.675	-3.310	47	.002	-.25053	.07570	-.40282	-.09824
	Equal variances not assumed			-3.316	46.862	.002	-.25053	.07555	-.40253	-.09854
DIV6PRE	Equal variances assumed	10.919	.002	-.063	40	.950	-.01594	.25277	-.52681	.49493
	Equal variances not assumed			-.061	27.815	.952	-.01594	.26004	-.54877	.51689
DIV6POST	Equal variances assumed	6.117	.017	-3.448	45	.001	-.56105	.16273	-.88881	-.23328
	Equal variances not assumed			-3.363	35.927	.002	-.56105	.16684	-.89943	-.22266
DSCON4PRE	Equal variances assumed	2.290	.139	-.828	34	.413	-.24007	.28981	-.82904	.34889
	Equal variances not assumed			-.902	32.879	.374	-.24007	.26620	-.78174	.30159
DSCON4POST	Equal variances assumed	2.625	.113	.998	39	.325	.20732	.20781	-.21302	.62766
	Equal variances not assumed			.915	23.660	.370	.20732	.22666	-.26084	.67549

DSCON6PRE	Equal variances assumed	2.675	.112	-.228	32	.821	-.04722	.20706	-.46899	.37455
	Equal variances not assumed			-.207	18.580	.838	-.04722	.22823	-.52564	.43119
DSCON6POST	Equal variances assumed	.156	.695	-.325	36	.747	-.06686	.20558	-.48380	.35008
	Equal variances not assumed			-.326	32.858	.746	-.06686	.20491	-.48383	.35011
DSDIV4PRE	Equal variances assumed	2.238	.144	4.946	34	.000	1.64502	.33259	.96911	2.32093
	Equal variances not assumed			5.173	32.958	.000	1.64502	.31800	.99801	2.29203
DSDIV4POST	Equal variances assumed	2.993	.092	4.329	39	.000	1.58960	.36719	.84690	2.33231
	Equal variances not assumed			4.369	35.435	.000	1.58960	.36386	.85126	2.32795
DSDIV6PRE	Equal variances assumed	6.038	.019	-.163	39	.871	-.07786	.47640	-1.04147	.88574
	Equal variances not assumed			-.173	36.885	.863	-.07786	.44939	-.98850	.83278
DSDIV6POST	Equal variances assumed	.168	.684	-1.025	43	.311	-.49635	.48427	-1.47297	.48027
	Equal variances not assumed			-1.028	41.292	.310	-.49635	.48286	-1.47130	.47860
SAC5PRE	Equal variances assumed	.863	.357	-2.838	48	.007	-.32731	.11532	-.55919	-.09544
	Equal variances not assumed			-2.838	47.390	.007	-.32731	.11532	-.55927	-.09536
SAC5POST	Equal variances assumed	.002	.969	-1.425	48	.161	-.14337	.10063	-.34571	.05896
	Equal variances not assumed			-1.425	47.999	.161	-.14337	.10063	-.34571	.05896
SAC10PRE	Equal variances assumed	.647	.425	-3.911	48	.000	-.84210	.21529	-1.27496	-.40923
	Equal variances not assumed			-3.911	44.969	.000	-.84210	.21529	-1.27572	-.40847
SAC10POST	Equal variances assumed	.732	.396	-1.889	48	.065	-.30931	.16372	-.63850	.01988
	Equal variances not assumed			-1.889	45.304	.065	-.30931	.16372	-.63900	.02038

APPENDIX D

PAIRED T-TESTS

Table D1 A table of statistical results from a Paired T-Test between before and after OBPT performed for all movements, for each movement's Latency. The tests with statistical significance are highlighted in green.

Latency			
	t	df	Sig. (2-tailed)
CON4	2.299	22	.031
CON6	1.980	21	.061
DIV4	1.598	21	.125
DIV6	1.824	20	.083
DSCON4	1.186	12	.259
DSCON6	.574	11	.578
DSDIV4	.549	17	.590
DSDIV6	1.711	14	.109
SAC5	1.367	24	.184
SAC10	1.373	24	.182

Table D2 A table of statistical results from a Paired T-Test between before and after OBVAT performed for all movements, for each movement's Latency. The tests with statistical significance are highlighted in green.

Latency			
	t	df	Sig. (2-tailed)
CON4	1.990	23	.059
CON6	1.810	20	.085
DIV4	-1.120	21	.275
DIV6	-.530	19	.602
DSCON4	1.207	20	.241
DSCON6	1.006	19	.327
DSDIV4	.252	23	.804
DSDIV6	-1.088	21	.289
SAC5	2.089	24	.047
SAC10	5.183	24	.000

Table D3 A table of statistical results from a Paired T-Test between before and after OBPT performed for all movements, for each movement's Time to Peak Velocity. The tests with statistical significance are highlighted in green.

Time to Peak Velocity			
	t	df	Sig. (2-tailed)
CON4	2.615	22	.016
CON6	1.416	21	.172
DIV4	1.452	21	.161
DIV6	.868	18	.397
DSCON4	.192	11	.851
DSCON6	-.397	10	.700
DSDIV4	-2.702	18	.015
DSDIV6	-.571	16	.576
SAC5	1.735	24	.096
SAC10	1.323	24	.198

Table D4 A table of statistical results from a Paired T-Test between before and after OBVAT performed for all movements, for each movement's Time to Peak Velocity. The tests with statistical significance are highlighted in green.

Time to Peak Velocity			
	t	df	Sig. (2-tailed)
CON4	3.627	23	.001
CON6	3.655	21	.001
DIV4	1.974	21	.062
DIV6	.299	18	.768
DSCON4	.670	21	.510
DSCON6	.573	19	.574
DSDIV4	.882	23	.387
DSDIV6	2.223	22	.037
SAC5	2.610	24	.015
SAC10	4.964	24	.000

Table D5 A table of statistical results from a Paired T-Test between before and after OBPT performed for all movements, for each movement's Peak Velocity. The tests with statistical significance are highlighted in green.

Peak Velocity			
	t	df	Sig. (2-tailed)
CON4	-3.041	22	.006
CON6	-2.058	21	.052
DIV4	-2.276	22	.033
DIV6	-1.439	20	.165
DSCON4	-.719	10	.489
DSCON6	-.980	12	.346
DSDIV4	-2.134	17	.048
DSDIV6	-.187	15	.854
SAC5	-.686	24	.499
SAC10	-.929	24	.362

Table D6 A table of statistical results from a Paired T-Test between before and after OBVAT performed for all movements, for each movement's Peak Velocity. The tests with statistical significance are highlighted in green.

Peak Velocity			
	t	df	Sig. (2-tailed)
CON4	-4.180	23	.000
CON6	-4.490	21	.000
DIV4	-6.070	21	.000
DIV6	-5.036	19	.000
DSCON4	-1.994	21	.059
DSCON6	-2.220	17	.040
DSDIV4	-1.912	23	.068
DSDIV6	-2.531	21	.019
SAC5	-1.156	24	.259
SAC10	-.074	24	.942

Table D7 A table of statistical results from a Paired T-Test between before and after OBPT performed for all movements, for each movement's Final Amplitude. The tests with statistical significance are highlighted in green.

Final Amplitude			
	t	df	Sig. (2-tailed)
CON4	.480	22	.636
CON6	-.050	21	.960
DIV4	-.100	22	.921
DIV6	.227	20	.822
DSCON4	-.031	11	.976
DSCON6	.028	12	.978
DSDIV4	-1.029	18	.317
DSDIV6	-.152	16	.881
SAC5	.336	24	.740
SAC10	-2.215	24	.037

Table D8 A table of statistical results from a Paired T-Test between before and after OBVAT performed for all movements, for each movement's Final Amplitude. The tests with statistical significance are highlighted in green.

Final Amplitude			
	t	df	Sig. (2-tailed)
CON4	-2.112	22	.046
CON6	-1.709	20	.103
DIV4	-.108	21	.915
DIV6	-1.793	19	.089
DSCON4	2.274	20	.034
DSCON6	-.286	17	.778
DSDIV4	-1.123	12	.283
DSDIV6	-1.089	22	.288
SAC5	1.878	24	.073
SAC10	.479	24	.636

APPENDIX E

BEHAVIORAL PLOTS

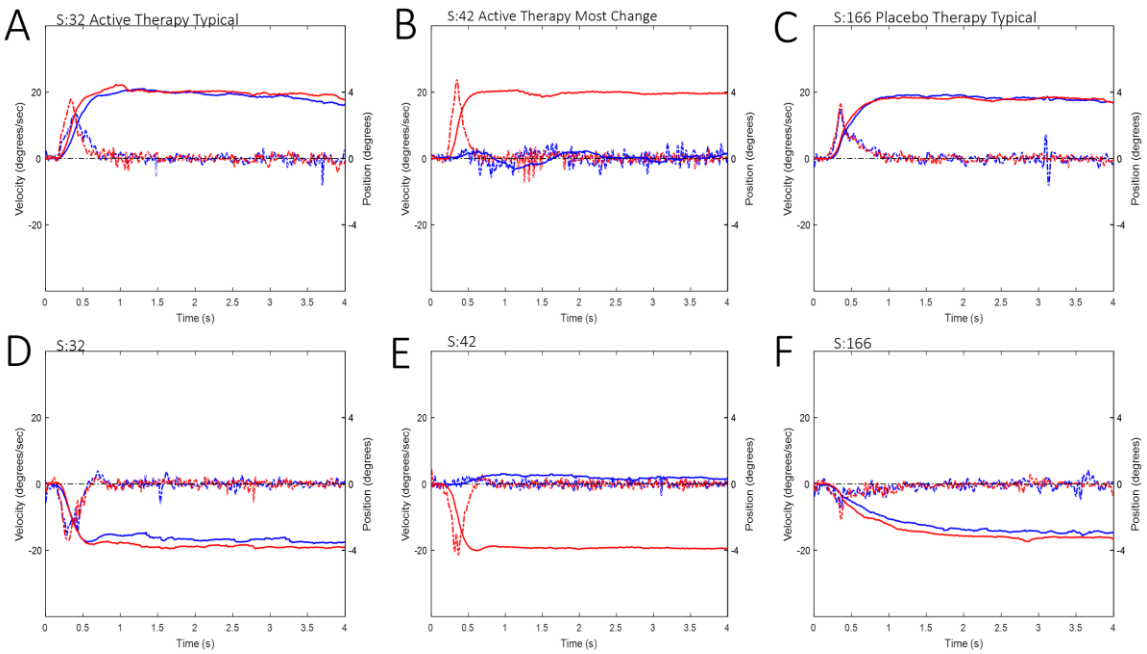

Figure E1 Behavioral plots of eye movements for CON4 and DIV4. The top row is the four-degree convergence movements, the bottom row is the four-degree divergence movements. The first column is a typical OBVAT participant. The middle column is the OBVAT participant with the most visible change. The last column is a typical OBPT participant. The dashed lines are the velocity plots, and the solid lines are the position plots. The blue lines are before therapy, and the red lines are after therapy.

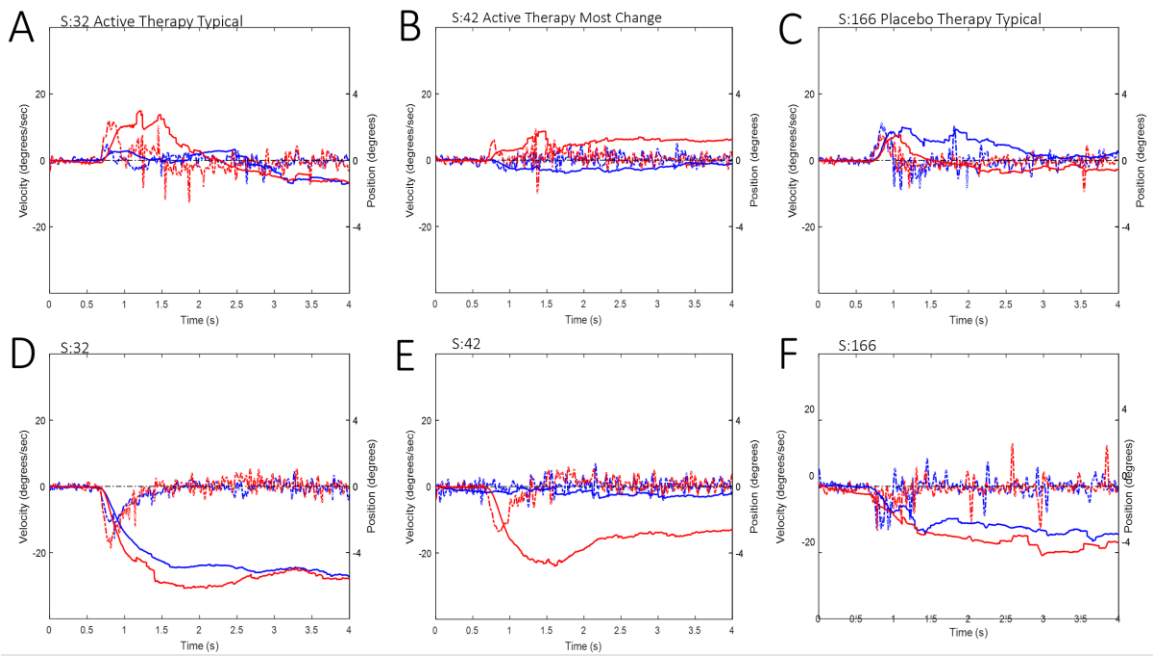

Figure E2 Behavioral plots of eye movements for DSCON4 and DSDIV4. The top row is the four-degree disappearing convergence movements, the bottom row is the four-degree disappearing divergence movements. The first column is a typical OBVAT participant. The middle column is the OBVAT participant with the most visible change. The last column is a typical OBPT participant. The dashed lines are the velocity plots, and the solid lines are the position plots. The blue lines are before therapy, and the red lines are after therapy.

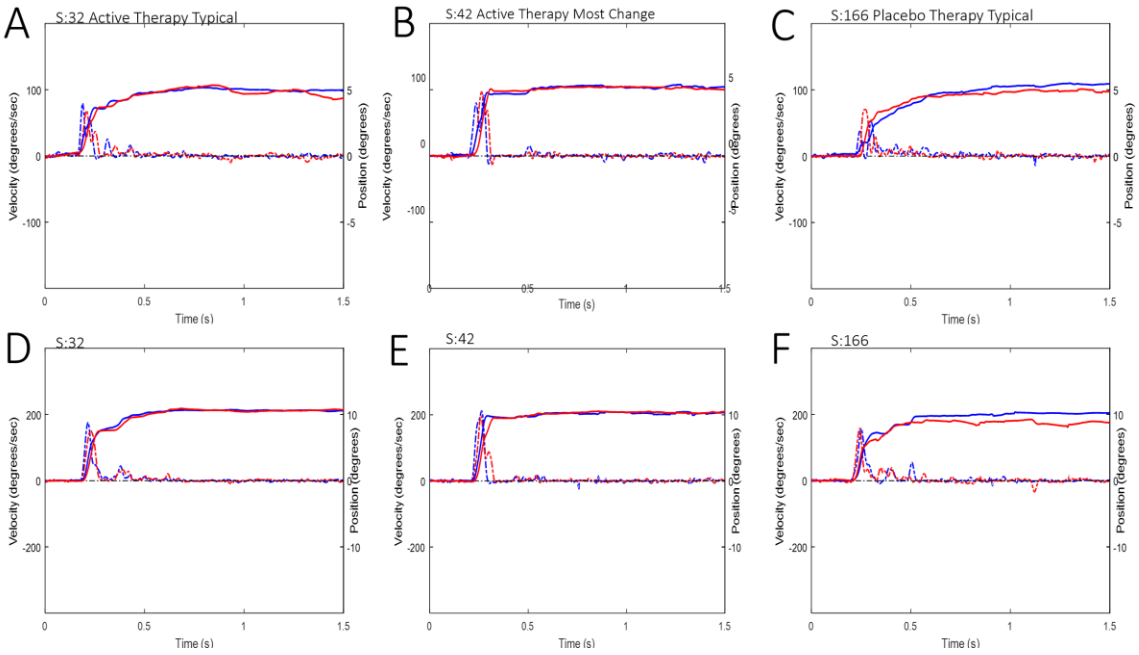

Figure E3 Behavioral plots of eye movements for SAC5 and SAC10. The top row is the five-degree saccadic movements, the bottom row is the ten-degree saccadic movements. The first column is a typical OBVAT participant. The middle column is the OBVAT participant with the most visible change. The last column is a typical OBPT participant. The dashed lines are the velocity plots, and the solid lines are the position plots. The blue lines are before therapy, and the red lines are after therapy.

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