Doctoral College at the University of Hertfordshire

PhD Dissertation

Evidence Based Criteria Diagnosis and Management of Decompensating Heterophoria

Submitted to the University of Hertfordshire in partial fulfilment of the requirement of the degree of Doctor of Philosophy

Natalia Rinsky

MRes Optometry and Vision Science

Principal Supervisor: Professor Fergal Ennis
Second Supervisor: Dr Joy Myint
Local-based supervisor: Dr Gulnara Kriger

July 2024

Acknowledgement

I extend my deepest gratitude to my esteemed supervisor, Professor Fergal Ennis, whose unwavering support, invaluable guidance, and relentless encouragement have been pivotal throughout my doctoral journey. His expertise and dedication have played a fundamental role in shaping this dissertation into fruition.

I am profoundly grateful to Dr. Yongju Huang, Research Tutor, for her steadfast assistance and invaluable input, which have greatly enriched this research endeavour.

I also extend my sincere appreciation to Dr. Joy Myint and Dr. Gulnara Kriger for their invaluable guidance and insightful feedback as my second supervisors. Their expertise and support have been invaluable in enhancing the quality and depth of this work.

Furthermore, I express my heartfelt gratitude to the Doctoral College Central Team for their administrative support and assistance throughout my doctoral studies. Their dedication and professionalism have facilitated the smooth progression of my research journey.

Lastly, I express my deepest appreciation to my family, particularly my husband, for their unwavering support, boundless encouragement, and enduring inspiration throughout my academic pursuits. Their steadfast belief in me has been the cornerstone of my success, and I am profoundly grateful for their unwavering presence on this journey.

To everyone mentioned above and to all those who have supported me along the way, I offer my sincerest thanks. Your contributions have been indispensable, and this accomplishment would not have been possible without your guidance, encouragement, and unwavering belief in my abilities.

Thank you all immensely.

Natalia Rinsky

Copyright and terms of use

Declaration

This project is submitted as part of the requirements for the PhD in Optometry and Vision Science module OP3207: Research in Optometry and Vision Science, School of Life and Medical Sciences.

All the work included in this submission is the author's original work, and where the ideas or work of other individuals have contributed, they have been referenced appropriately.

The PhD program began in August 2020. The Ethical Approval Notification was received on November 11th, 2022. The delay in obtaining the ethical approval was due to COVID-19. Moreover, the clinical practice was limited due to COVID-19, which led to an increase in the timing of the study and limited the time frame and, therefore, the ability to fully develop some of the experiments of this research.

Table of Contents

Appendices

PAG

List of Figures, Flow Charts and Pictures

List of Tables

The Table **PAG**

List of Abbreviations

AC/A	Accommodative-Convergence to Accommodation ratio
BI	Base In
BO	Base Out
CI	Convergence Insufficiency
CISS	Convergence Insufficiency Symptoms Survey
CPM	Cycles Per Minute
CT	Cover Test
D	Diopter
FD	Fixation Disparity
FDC	Fixation Disparity Curve
FR	Fusional Reserves
FVA	Fusional Vergence Amplitude
NFR	Negative Fusional Reserves
NPC	Near Point of Convergence
NRA/PRA	Negative Relative Accommodation / Positiva Relative Accommodation
OD	Oculus Dexter
OS	Oculus Sinister
PAT	Prism Adaptation Test
PD	Prism Diopter
PFR	Positive Fusional Reserves
ROC	Receiver Operating Characteristic
SC	Stereopsis compromised
SN	Stereopsis-Normal
SOA	Seconds of Arc
SPC	Stereo Prism Criterion
SVA	Slow Vergence Adaptation
VA	Visual Acuity
VF	Vergence Facility
VT	Vision Therapy

Abstract

Introduction: Decompensating exophoria at near is a common condition in optometry practice. The main treatment options for the disorder are relieving prism and Vision Therapy. The prism prescribing techniques are usually derived from two methods: the FD method or the FR method. Neither of these methods is entirely successful. A more recently acknowledged clinical observation in decompensating heterophoria is a reduction in stereopsis. This project aims to investigate the incorporation of global stereopsis testing in prism prescribing for heterophoria.

Materials and Methods: A total of 185 participants were recruited. A Stereo Prism Criterion (SPC) was developed: the minimum prism to achieve maximum global stereoacuity on TNO. A relieving prism was prescribed according to Sheard's Criterion, SPC and FD methods in double-blind crossover studies. 35 participants subsequently underwent VT. The participant's satisfaction was evaluated using a symptom-based questionnaire.

Results: The SPC contributed to a higher prism than Sheard's and FD ($p<0.01$) and to greater symptom relief ($p<0.01$). The TNO is more affected by heterophoria decompensation than local stereo tests. Unlike the other two methods, the SPC prism resulted in a normal level of symptoms ($p<0.01$). VT using this prism helped reduce signs of decompensation, including symptoms ($p<0.01$), and improve stereoacuity ($p<0.01$).

Conclusion: The TNO test, known for its sensitivity to decompensating exophoria, has provided a better relieving prism than the commonly used Sheard's criterion and the FD method. Importantly, the level of symptoms approached that of normal patients without any statistical difference. This suggests that SPC for prescribing prism can be recommended to be used in optometry practice.

1. Introduction

1.1. Background

Binocular vision refers to the ability to use both eyes together to perceive depth and see a single, unified image of the world. This system relies on the fact that each eye views the world from slightly different angles, and the brain combines these two slightly different images into one three-dimensional representation. Normally, a clear image forms on the right and left retina of the eyes, and high-resolution stereopsis is provided by an efficient binocular visual system. Binocular vision integrates information from two eyes to the brain regarding the same visual field region to perceive the three-dimensional world (Portela-Camino, 2021). Binocular processing primarily occurs when neurons receiving information from the two eyes converge on common cells in the primary visual cortex. (Başgöze, Mackey & Cooper, 2018).

Binocularity is a basic component of a normal human's visual function and has several advantages in everyday life over monocular vision, which can provide no stereovision (Askarizadeh, Heirani, Khorrami-Nejad, Khabazkhoob & Narooie-Noori, 2022). It enables the discrimination of relative distance between objects and allows the viewer to understand the direction of movement and speed of objects in the visual scene (Portela-Camino, 2021; Mishkin, Ungerleider & Macko, 1983). Binocular summation is another major benefit, which offers a higher visual acuity (Frisén & Lindblom, 1988) as well as a higher contrast sensitivity (Banton & Levi, 1991) and faster processing speed of visual stimuli (Woodman, Young, Kelly, Simoens & Yolton, 1990).

Different techniques are used to assess the local and the global stereopsis (see 1.3). The local stereopsis depends only on the central vision. Therefore, it has a narrow field and a small viewing angle (Fortin, Ptito, Faubert & Ptito, 2002). The local stereopsis uses two similar targets that are laterally displaced. Stereo tests with these types of targets can enable the patient to use monocular cues (like colour and contrast) to detect the form from the background. These cues promote a false positive error. In this horizontal retinal disparity analysis process, there is no need for any reference to other parts of the retinal field (Julesz, 1978).

1.2. Stereopsis

Stereopsis is defined as the perception of depth from binocular horizontal retinal disparity and involves a complex neural interaction between sensory and motor processes (Wajuihian, 2020; Matthews, Hill & Palmisano, 2012; Ancona et al., 2014; Fricke & Siderov,1997). The interpupillary distance between the two eyes provides slightly different points of view of the same visual scene. This difference provides a horizontal retinal disparity expressed in seconds of arc. Horizontal retinal disparity provides information to the visual cortex, from which arises the perception of depth (Fricke & Siderov, 1997). Stereo acuity is the highest form of binocular coordination that can be measured.

The objective of the visual system is to determine and localise the objects present in the field of view (Mishkin et al., 1983) and to detect the distance to these objects. Stereopsis is a type of depth perception that enables one to perceive the world in three dimensions (Richards, 2009). It is the ability to perceive depth from the binocular discrepancies, which is a difference between the positions of matching features on the retina (Cumming & DeAngelis, 2001).

In fact, monocular cues can help determine the distance from one object to another and understand which object is closer and which is farther away. However, binocular vision is much more functional than monocular vision. High-quality stereovision gives the advantage of a faster visual response - the viewer with high stereopsis will perceive objects faster and more accurately than a viewer with low stereopsis. Binocular summation results from having two visual inputs of the same visual scene simultaneously, providing a higher visual acuity (Blake, Sloane & Fox, 1981) and a higher contrast sensitivity (Frisén & Lindblom, 1988).

Jones and Lee (1981) have demonstrated in their research that subjects performed the most widely varied tasks more effectively under binocular rather than monocular viewing conditions. The tasks included in their study were identifying letters, detecting camouflaged octopuses, discriminating among colours, bead threading using closed-circuit TV, tracking a moving target using closed-circuit TV, controlling stance, needle threading, and water pouring. Not all of the tasks involved stereopsis. Howard and Rogers (2012) have reported that binocular vision and stereopsis, in comparison to

monocular vision, are more powerful. To catch a ball or hit it in a timely manner, the visual system must be able to judge the time to collision. Prompt awareness allows enough time for an appropriate motor response (Howard & Rogers, 2012). Therefore, stereovision provides better motor control than monocular vision (Gray & Regan, 1998). Stereovision is also vital in various situations, ranging from highway driving to aviation. There is evidence that compromised stereoacuity is associated with an increased risk of cognitive functions (such as visual-spatial skills, calculation, recall, orientation, registration, and attention) decline in the elderly population (Swenor et al., 2019). Moreover, patients with neurodegenerative diseases stereovision like Parkinson's disease have a violation of spatial perception, such as impaired visuospatial perception (Tiwari, Paul & Paritekar, 2017).

Stereopsis relies on accommodative and vergence systems (binocular alignment) and high and similar visual acuity (Leshno, Stolovitch, Zloto, Meirovitch & Mezad-Koursh, 2021) and occurs in the cerebral cortex. The neurological pathway from both retinas is complex and travels through the visual pathway to reach the visual cortex or striate cortex. The entire pathway should function normally to achieve the three-dimensional image (Lee, Moon & Cho, 2014b).

The visual system has to provide information about a three-dimensional scene from two-dimensional retinal images. Since the two eyes have different vantage points, the two retinal images are not identical. Retinal image disparity triggers fusional movements, which occur to eliminate retinal disparity. However, after a fusional movement, a small disparity remains. Stereopsis occurs when two horizontally disparate retinal images are fused within Panum's area.

Since subjects with decompensating phoria are likelier to have reduced stereoacuity, it can indicate compensation status. However, stereo acuity under prismatic stress seems to be a more valid argument for symptomatic subjects than the fixation disparity curve (Kromeier, Schmitt, Bach & Kommerell, 2003). Therefore, stereoacuity should also be considered when prescribing a relieving prism for decompensating heterophoria.

1.3. Global and local stereopsis

Stereopsis takes place in the cerebral cortex. The neurological pathway from the right and the left retina, where the object's image is formed, is complex. The neurological signal travels through the optic nerve to the lateral geniculate body, then to the optic radiation, and, in the end, it reaches the visual striate cortex. The entire pathway should function normally to reach the three-dimensional picture (Lee, Kim & Yu, 2014a).

It is important to note that there are two types of stereopsis: local and global. Both originate in the Occipital cortex V2 and extend to the extra-striate areas. (Qiu & Heydt, 2005). Global stereopsis occurs when the perception of the whole object in three dimensions is achieved via disparity processing over a large visual area without needing the identification of local features. For local stereopsis, the object's localised features need to be extracted from each retinal image and local disparities are processed to extract stereopsis (Rowe, 2012). This type of stereopsis does not need reference to any other part of the retinal field when the horizontal retinal disparity assessment process occurs (Fricke & Siderov, 1997).

Global stereopsis relies on disparity-selective neurons (Cumming & DeAngelis, 2001) and specialized neurons in the right occipital lobe (Hamsher, 1978). In contrast, local stereopsis involves different neural substrates (Frisby, Mein, Saye & Stanworth, 1975). Table 1 summarises the difference between local and global stereopsis.

The difference between local and global stereopsis		
	Local	**Global**
When does occurs	The images must be similar and must correspond to each other in order for the two to enable the match (Julesz, 1978; Vancleef et al., 2017). It occurs when localised features of objects are extracted from a visual scene and assigned relative depth values, indicating that one feature is	After local stereopsis has occurred, the higher-order mechanism, Global stereopsis, matches elements of the found clusters to extract further depth information. The visual system has to perform an interocular image disparity interaction across a considerably extended binocular visual field

	further away from another (Rowe, 2012).	(Benjamin & Borish, 2006, chapter 5). Global stereopsis occurs when the perception of whole objects in stereoscopic depth is achieved (Julesz,1978).
Depends on	Depends on the horizontal retinal disparity analysis process from monocularly seen stimulus patterns. This process does not need any reference to other parts of the retinal field (Saladin, 2005; Julesz, 1978). The process requires a limited and relatively simple match of similar image features (Chopin, Silver, Sheynin, Ding & Levi, 2021).	A complex process of binocular matching is required to achieve consistent depth perception (Chopin). Horizontal retinal differences must be correlated over a relatively wide area for global stereoscopic vision to occur (Fricke & Siderov, 1997). It depends upon the horizontal disparity patterns, which are not seen monocularly. Those patterns cause binocularly observable figures and depth perception (Saladin, 2005).
The test targets	Part of the targets has monocularly visible cues and forms which can be distinguished from the background monocularly (Benjamin & Borish, 2006, chapter 5; van Doorn et al., 2014). Since the contours that define the target shapes are typically visible, it is not necessary to see those shapes, only the contour (Chopin, Silver, Sheynin, Ding & Levi, 2021). In response to monocularly visible contours, the fusion mechanism reduces the need for accurate motor control (Clarke & Noel,	The shapes that are defined by depth cannot be seen monocularly and can only be detected binocularly. Only after the correspondence problem is solved does the 3D image appear (Chopin, Silver, Sheynin, Ding & Levi, 2021; van Doorn et al., 2014). The global stereo-target is required for an accurate bifoveal fixation and visual alignment (Clarke & Noel, 1990).

	1990). This makes it easier to achieve high results in a local test (Frisby, Mein, Saye & Stanworth, 1975).	

Table 1: the difference between Local and Global stereopsis.

There is no agreement regarding whether a single or separate system performs the neural analysis of global and local stereopsis. Chopin et al. (2021) recruited five adults with amblyopia who had no global stereopsis and conducted training using a computerised local stereopsis depth task for twelve hours on average. Three participants had better initial local stereopsis performance and less severe amblyopia. After the training, those participants recovered fine global stereoscopic vision, improving the local stereopsis. The authors demonstrated that by training the local stereoacuity, global stereoacuity improves, which suggests a transfer of learning from local to global. This meant that local and global stereopsis is an interacting two-stage compatible model. Gantz & Bedell (2010) trained fourteen subjects with normal binocular vision using either local or global random dot stereogram stimulus. The authors concluded that since the rate of improvement was with no statistical difference between the local and global training groups and since there was a transfer of the perceptual learning, the neural mechanism of global and local stereopsis is completely the same. However, these conclusions have been criticised by Chopin et al. (2021), who insisted that the transfer of perceptual learning from local stereogram to global supports the idea of a single mechanism for stereopsis but with two interacting stages. Chopin et al. (2021) stated, “At one stage, a solution for the binocular correspondence problem is selected, and at the other stage, binocular disparities are extracted based on this particular solution.” (p. 2).The existence of two separate neural systems responsible for stereopsis comes from the study of the effect of cortical lesions. A study by Ptito, Zatorre, Larson & Tosoni (1991) demonstrated that local and global stereopsis have a neural dissociation. Forty-four patients with unilateral anterior temporal lobe excisions as an epileptic seizure treatment and 23 normal control subjects were assigned to the local and global stereopsis tasks using random-dot stereograms. The local task had no threshold impairment, and the global was significantly impaired. The authors concluded that the neural mechanisms involved in local and global stereopsis are not identical but related. They stated that the striate cortex has a hierarchical organisation of the visual pathways, from the striate cortex to the temporal cortex.

Using a prism-rearing procedure, Nakatsuka et al. (2007) induced strabismus in five macaque monkeys between 4 and 14 weeks of age. Three monkeys were assigned for local stereoacuity tasks training around two years of age. Before the training, tests revealed that the monkeys were not amblyopic but lacked binocular summation. All three monkeys, after the training, showed improvement in stereoacuity. Moreover, neurons in the V2 area (but not V1) retained significantly better sensitivity for disparity in comparison to neurons in monkeys who were not trained. Global stereopsis is more vulnerable to certain binocular anomalies than tests based only on local stereopsis since global stereo needs both fine and coarse stereopsis functions (Benjamin & Borish, 2006, chapter 1). These findings suggest local stereopsis may remain in monkeys with an early-onset strabismus. Pageau, Saint-Amour & de Guise (2011) reported that local stereopsis is present in micro-strabismic cases, but global stereopsis is generally absent and concluded that some neurological diseases and early onset strabismus have a different impact on the local and global stereopsis.

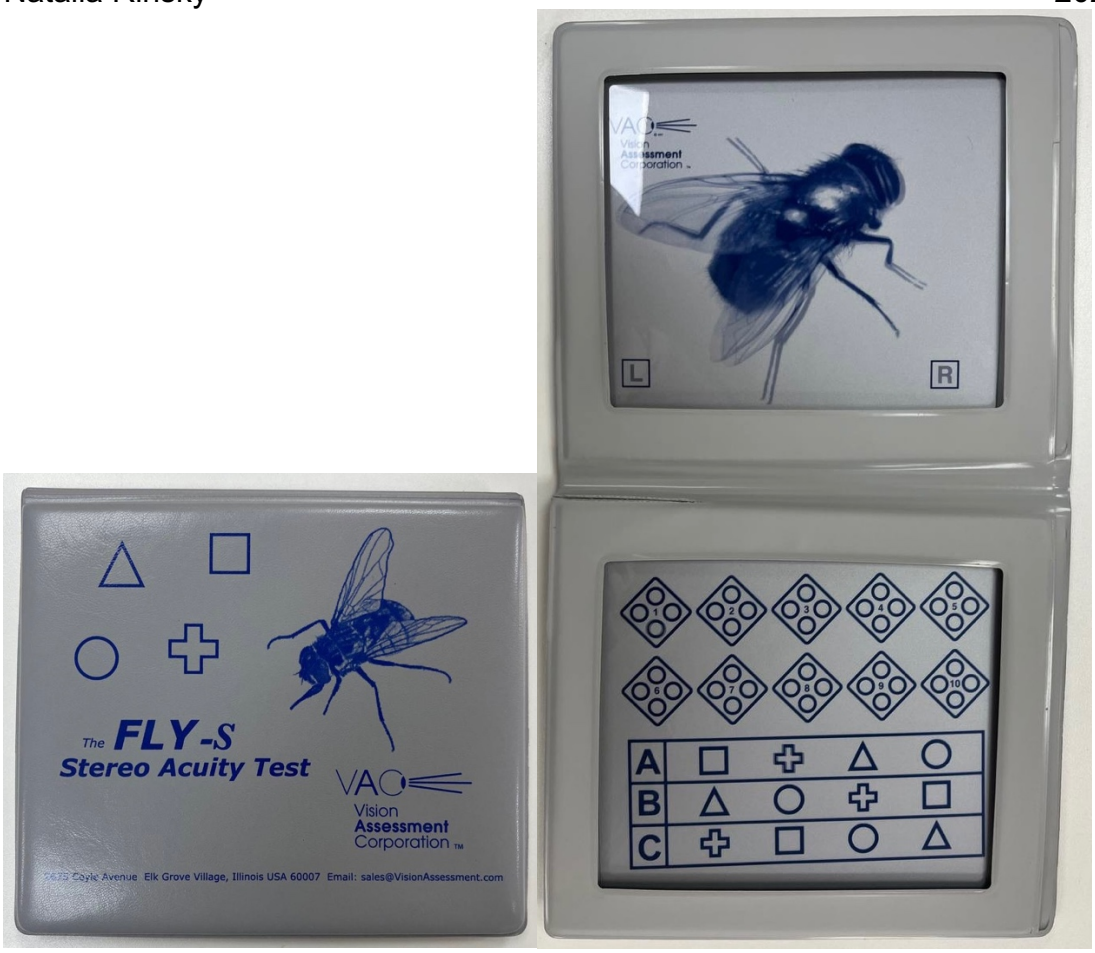
Chopin et al. (2021) conducted a preliminary study with five amblyopic adults lacking global stereopsis. The participants were trained on a computerised local stereopsis depth task. After twelve hours of training, an average of sixty per cent of the participants recovered fine global stereoscopic and reached the local stereopsis task more quickly. Also, they tend to start the training with less severe amblyopia and better initial local stereopsis performance. It means that local stereopsis improves quicker than global stereopsis. Momeni-Moghadam, Kundart, Ehsani & Gholami, (2011) recruited 170 students with no strabismus. The participants were divided into two groups according to the presence or absence of near-binocular vision symptoms. Stereoacuity using Titmus and TNO stereotests was measured. The global stereopsis was more compromised in the symptomatic group than the local stereopsis. The authors concluded that global stereotest was more helpful in differentiating between symptomatic and asymptomatic individuals. Momeni-Moghadam et al. (2011) determined that TNO measures higher thresholds across individuals with decompensating heterophoria than Titmus. This is evidence that in decompensating heterophoria, there was a difference in the level of local versus global stereoacuity. However, Momeni-Moghadam et al. (2011) study the stereotests were not used as a decompensated heterophoria treatment, but only as a screening test. On the other hand, in the current study, SPC is based on the global stereopsis.

1.4. Stereo tests

Several stereo tests are available on the market, mostly for near testing distances. Since the methods, conditions and the chosen threshold used in these tests are different, it is hard to compare the results of one stereoacuity test to the other. Saladin (2005) has noted that stereoacuity tests can be divided into two groups, random dot and contoured. The more common tests that are practised in optometry are vectographic and anaglyphic. The vectrographic test uses polarised filters, while the anaglyphic test uses red-green filters (Momeni-Moghadam, Kundart, Ehsani, & Gholami., 2011; Fricke & Siderov,1997). Both types of filters separate the images seen by the right and the left eye. Another test is the Frisby, which is said to be a real depth stereotest. Since the test requires no dissociative glasses, it is less artificial (Antona, Barrio, Barra, Gonzalez & Sanchez, 2015).

1.4.1. Titmus

The Titmus Stereo Test (Picture 1), also known as the Wirt Stereo Test, is a vectograph test in which the two targets are polarised at 90 degrees relative to one another and are seen through polaroid filters (Lee & McIntyre, 1996). The test consists of three parts: the Fly, the Animals, and the Wirt Rings. The wings of the fly are seen at 3000 seconds of horizontal disparity. The animals row A has 400 seconds of horizontal disparity; row B has 200, and row C has 100. The Wirt Rings Test has three groups of four rings from 800 to 40 SOA. The test has a contour target, and it has monocular form cues (Fawcett & Birch, 2003). Each test part involves monocularly visible contours (Fricke & Siderov 1997).



Picture 1: *Titmus (Fly) Stereotest.*

The Titmus test has some monocular cues readily apparent in at least the first four sets of Titmus circles. Non-stereoptic lateral displacement occurs when the test is viewed monocularly through polarised lenses. (Fawcett & Birch, 2003). These monocularly visible contours allow a stereo-blind patient to pass the test up to set 4, a disparity of 140 SOA, with only one eye open (Simons & Reinecke, 1974; Reineck & Simons, 1974; Levy & Glick, 1974; Clarke & Noel, 1990; Schweers & Baker, 1992; Rutstein et al., 1984; Fricke & Siderov 1997).

1.4.2. Randot

The Randot 2 Stereo Test with Lea Symbols (Picture 2) uses a vectographic method to present disparity. The patient is required to wear polarised filters, which contain random dot ground. This test consists of three parts: the Expanded Random Dot Lea Symbols, the LEA Symbols, and the Graded Circle test. The first part of the test comprises four levels of gross disparity. It consists of four sets of four squares, 3 of

which contain one of Lea's symbols (a house, a square, a circle or an apple). One of the four squares is blank. These four sets are named A, B, C and D, and the horizontal disparities are 500, 250, 125 and 63 SOA, respectively. The second part of the test contains three levels of disparity: 400, 200 and 100 SOA. There are three rows of four Lea symbols. The last part of the Randot Stereo Test is the Graded Circle Test, which consists of twelve sets of three circles with a disparity from 400" down to 12.5 SOA. The Randot stereotests and the Titmus test contain some monocular form cues (Fawcett & Birch, 2003). However, Randot gives fewer monocular cues than the Titmus test (Lee & McIntyre, 1996).

Picture 2: *Randot Stereotests with Lea symbols.*

In the same way as in the Titmus test, in Randot tests, the monocular cues allow a false positive answer up to a disparity of 140 SOA (Simons & Reinecke, 1974; Reineck & Simons, 1974; Levy & Glick, 1974; Clarke & Noel, 1990; Schweers & Baker, 1992; Fricke & Siderov 1997).

1.4.3. TNO

The TNO stereoacuity test (Picture 3) was designed by the Netherlands Organisation for Applied Scientific Research (Doorn et al., 2014). Lameris Ootech published its first edition in 1972 (Lameris Instrumenten, Groenekan, Netherlands). Over the years, no obvious changes have been made to the test or the (Lam, Tse, Choy & Chung, 2002).

Picture 3: *TNO Stereotest, edition 15.*

The TNO test is an anaglyphic test, requiring the patient to wear the red/green filters in order to separate the images seen by the right and left eyes. The test uses random-dot patterns to present gross disparity. It consists of seven different plates. The first three plates enable the examiner to establish whether the stereovision is present or not. Plate four allows us to check whether suppression occurs or not. These plates are used for screening needs. Each has a monocularly visible shape, so patients who cannot detect the disparity do not know that the test failed (Fricke & Siderov 1997). Plates five, six and seven are quantitative plates. They contain no monocularly visible features (Fricke & Siderov 1997) and enable the examiner to measure the stereoacuity. The test figure is a disc with a section missing, and the patient must locate the disc's missing sector. This test figure is present on six different depth levels with retinal disparities from 480 to 15 SOA. Plate five has two test figures with a finer disparity threshold of 480 and two of 240 SOA. Plate six has two test figures of 120 and two of 60 SOA. Finally, plate seven has two test figures of 30 and two of 15 SOA.

1.4.4. Frisby

The Frisby stereo test (Picture 4) presents real depth targets and performs without filter (Garnham & Sloper, 2006). It consists of three transparent plates, six, three and one and a half millimetres thick. On each plate, four target squares are printed on one of the sides with a randomly arranged pattern of arrowheads of different sizes. Similar pattern elements are printed around each target on the other side of the plate. A patient with normal binocular vision can detect the target since it appears to stand out from the background. Fusion allows the distinguishment of the stereotest contour. To avoid monocular parallax clues, there is a need to ensure that the subject does not tilt or move the plate while being tested (Garnham & Sloper, 2006). If the test is performed properly, a patient lacking stereoacuity will fail. The test can be performed at different distances to measure the stereoacuity range. The test is provided with a stereoacuities octave-based table that provides the distance combinations for each plate. The table covers a stereo acuity range of 5 10, 20, 25, 30, 40, 55, 75, 85, 110, 150, 170, 215, 300, 340 and 600 SOA. To avoid bias, the plates should be shown one by one and placed about 5-10cm in front of a clear background stationary (Frisby, 1980). The published studies show that a normal stereo acuity measured with Frisby for young adults is 20-sec arc or better (Frisby, 1980). Since the Frisby stereotest has relatively large texture elements, it is often easier for patients to deal with than Randot tests (Frisby, 1980).

Picture 4: *Frisby Stereotest*.

1.5. Stereotest comparison

As was said previously, the presence of monocular cues in local stereotests might assist in the appropriate vergence of motor fusion (Frisby, 1980), which reduces the need for accurate motor control. Fawcett (2005) conducted a study to compare Titmus and Randot stereo test results among participants with normal binocular vision and abnormal. Ninety-one participants with abnormal binocular vision and fifty-four normal subjects were included. The means stereoacuity scores of normal participants with the Titmus (40 SOA) and Randot (20 SOA) were not significantly different, as well as among the abnormal participant group (Titmus 50 SOA; Randot 70 SOA).

In real-world scenarios, depth judgments are primarily based on disparities in the actual contours of observed objects. This is more comparable to the stimuli used in the Titmus stereo test than those in the TNO test (Garnham & Sloper, 2006). Saladin (2005) has noted that stereoacuity tests can be divided into two groups, random dot and contoured. Antona et al. (2015) found that the repeatability of Frisby, TNO, Randot and Titmus tests was low among subjects with abnormal binocular vision and yet fairly good in participants with normal binocular vision except for the TNO Ancona et al. (2014) conducted a survey comparing Lang I, Lang II, Titmus, and TNO to reveal the best strabismus screening tool. Fifty-nine strabismic and eighty-four normal children were tested with Lang I, Lang II, Titmus, and TNO stereotests. TNO showed to have lower sensitivity (79.7% (67.6–88.1)) but a higher specificity 86.9% (77.9–92.7) than Titmus (sensitivity 83.1% (71.3–90); Specificity 83.3% (73.8–89.9)). Ohlsson et al. (2001) demonstrated the inability of Titmus, Randot, Frisby, and TNO tests to detect amblyopia and strabismus. Momeni-Moghadam et al. (2011) compared the stereopsis with TNO and Titmus in symptomatic and asymptomatic students. They found that a higher threshold was with Titmus than with TNO in both groups. Table 2 summarises the repeatability and validity of the stereoacuity tests among subjects with normal and abnormal binocular vision.

Stereotests repeatability and validity among subjects with normal and abnormal Binocular Vision				
	Repeatability of participants with normal BV	Repeatability of participants with abnormal BV:	Sensitivity	Specificity
Frisby	± 13 SOA	± 69 SOA		
Titmus	± 12 SOA	± 91 SOA	83.1% (71.3-90)	83.3% (73.8-89.9)
Randot	± 23 SOA	± 72 SOA		
TNO	± 54 SOA	± 120 SOA	79.7% (67.6-88.1)	86.9% (77.9-92.7)

Table 2: Stereotests repeatability and validity (Antona et al., (2015); Ancona et al. (2014)).

1.6. Heterophoria compensation status evaluation using stereoacuity

Heterophoria has long been known as a potential cause of binocular vision symptoms and is covered in detail in all good binocular vision textbooks (Section 11.2). A brief introduction to the subject is included here.

Reduced stereo acuity indicates a binocular vision system under stress and is often listed as a sign of decompensated heterophoria. Ukwade, Bedell, & Harwerth (2003) demonstrated that reduced stereoacuity is associated with FD, and the stereo threshold increases with an increase in the magnitude of the forced vergence demand. A small survey showed that in seven out of eight participants, the stereoacuity was lower under prismatic stress before the participant reported diplopia (Kromeier et al. 2003). The results of clinical studies indicate that stereovision decreases with phoria decompensation. However, not many published stereo accuracy thresholds indicate the level of phoria compensation. For this reason, the present study aims to identify the implications of stereoscopic vision in evaluating the phoria compensation status.

Both types of stereovision should be assessed to evaluate the phoria compensation status. Different techniques are used to assess both the local and the global stereopsis. Since global stereopsis seems more sensitive to phoria

decompensation than local (Momeni-Moghadam et al., 2011), this type of stereovision should play a major role in calculating the relieving prism in decompensating heterophoria.

1.7. Heterophoria compensation status

The brain receives input from each eye simultaneously and, under normal viewing conditions, can fuse the image formed on each retina into a single percept. The visual axes of two eyes are normally parallel to each other in the primary position of gaze when looking at a distant object. This perfectly aligned position is called orthophoria. On the other hand, a manifest misalignment of the visual axes is named heterotropia (“tropia”), when the two eyes are no longer directed towards the same single object of regard, and hence double vision (“diplopia”) will occur. A more common condition is the latent form of heterotropia called heterophoria (“phoria”), which is present in 70%–80% of the population (Kriz & Skorkovska, 2017; Kommerell & Kromeier, 2002) and is not influenced by uncorrected refractive error or age (Babinsky, Sreenivasan & Candy 2015). Phoria is a neural and mechanical imbalance in binocular alignment, which is compensated by motor fusion, and hence, double vision is avoided. When the vergence mechanism maintains a perfect alignment of the visual axes during binocular viewing conditions, heterophoria is said to be "compensated", and the patient is asymptomatic. When the deviation angle increases and the motor fusion system - Fusional Reserves (FR) - can no longer overcome the deviation, the heterophoria will “break down” to a heterotopia, which is described as “decompensated”, and diplopia will occur. When the vergence mechanism is struggling but most of the time maintains alignment, the phoria can be described as “decompensating”.

A proper alignment of the right and left visual axes is essential in extracting depth perception from the retinal images. Individuals who suffer from a poor phoria/vergence relationship may be unable to retain a bi-foveal fixation (heterophoria). As a result, they may be unable to maintain clear, comfortable binocular vision. Even if the amount of heterophoria is large, the Slow Vergence Adaptation (SVA) mechanism can compensate for it, and there will be no symptoms (Garzia & Dyer, 1986). However, the fixation disparity (a small deviation of the eyes under binocular viewing conditions (Chin, 1969) will increase if the SVA mechanism is not strong enough. As a result, the SVA

mechanism will be fatigued (Garzia & Dyer, 1986), and the heterophoria will be decompensated.

A decompensating exo deviation at near is the most common binocular vision disorder, with an estimated prevalence of 3%– 13% in the adult population (Montés-Micó, 2001; Clark & Clark, 2015; García-Muñoz, Carbonell-Bonete, Cantó-Cerdán & Cacho-Martínez, 2016; Hashemi et al., 2017). This binocular vision anomaly is frequently linked to various vision-related symptoms, particularly during near activities. It can negatively impact occupational, educational, and athletic performance, ultimately reducing patients' quality of life (García-Muñoz et al., 2014; Rouse et al., 2004). In addition, symptoms such as discomfort under binocular viewing conditions, intermittent diplopia, asthenopia, blurred vision, headaches, difficulties with stereopsis or other critical visual tasks, etc., are associated with decompensated deviation. Even though headache or intermittent diplopia and many other symptoms are not unique to decompensating exophoria (Rae, 2015).

Even minor levels of decompensating heterophoria can result in visual symptoms (Przekoracka-Krawczyk et al., 2019). Inversely, the deviation angle cannot predict symptoms (Sheard, 1934), and Yekta, Pickwell and Jenkis (1989) reported no statistically significant relationship between the deviation angle and symptoms. It is essential to discriminate the phoria compensation status to provide investigation and management when needed (Policar, 2018). The heterophoria compensation status was determined by the following criteria: Symptoms, the deviation angle, CT recovery movement, FR in conjunction with Sheard’s criteria, FD and prism adaptation.

Symptoms of decompensated heterophoria can be classified into three categories: visual perceptual distortions, binocular factors, and asthenopia factors. Visual perceptual distortions encompass blurred vision, diplopia, and distorted vision. Binocular factors include challenges with stereopsis, monocular comfort, and focus adjustments. Asthenopia factors comprise headaches, eye pain, eye soreness, and general irritation.

The stereo test can help establish the presence of binocular vision and examine its quality. Rutstein, Fuhr and Schaafsma (1994) have reported that stereoscopic perception may be reduced in decompensated heterophoria cases. Patients often do

not complain about the reduction of depth perception because many monocular clues enable some level of depth perception.

1.8. Motor and sensory fusion

Motor and sensory fusion have to interact in agreement with each other to maintain phoria compensation. The motor fusion is provided by six pairs of extraocular muscles that have to move the eyes in conjunction and then maintain the alignment of visual axes. Bi-foveal fixation is maintained over changing distances when vergence movements of the eyes rotate them in opposite directions: both in for convergence, both out for divergence. Only if motor fusion is achieved does sensory fusion have the opportunity to occur. Sensory fusion must fuse and interpret the two retinal images to form one cortical image. If a normal retinal correspondence is present, stimulation of corresponding retinal points or areas by the same object produces a single vision (Rae, 2015).

The status of motor and sensory fusion is used to determine phoria compensation status through Fixation Disparity (Section 1.10), Fusional Reserves (Section 1.9), stereopsis, etc. (Rae, 2015).

1.9. The motor approach in phoria compensation status

Various approaches have been used to determine whether a phoria is compensated. Some assess the motor system, and some consider the sensory system. The phoria needs to be treated in cases of decompensation when the binocular vision system cannot adequately overcome the deviation by applying fusional vergence. If the effort is too great, the phoria becomes decompensated (Tang & Evans, 2007).

The first approach based on the capabilities of the motor fusion system was suggested by Landolt (1886) to measure Fusional Vergence Amplitude (FVA), which is the ability of the oculomotor system to maintain sensory fusion while overcoming varying vergence demands (Archer, 1986). There are positive and negative Fusional Reserves FRs that reflect the FVA. FRs are the maximum capacity of a person's vergence effort in reserve (convergence is a positive FR, and divergence is a negative FR) that can be used to overcome heterophoria while maintaining single binocular

vision (Conway, Thomas & Subramanian, 2012). Based on the FR, Percival and Fox (1922) and later Sheard (1930) made an attempt to establish criteria for acceptable values and calculate the relieving prisms. Clinical trials demonstrate limited agreement between the Percival and Sheard criteria. Moreover, the criteria mentioned above are based only on motor skills rather than considering the sensory component. Therefore, these approaches should be revised, and in the current study, the upcoming criterion will include both motor and sensory components.

1.10. The sensory approach in phoria compensation status

Fixation Disparity (FD) is a sensory binocular vision function used to assess the phoria compensation status. FD occurs when one eye's fovea is slightly misaligned, while binocular fixation occurs (London & Crelier, 2006). When a phoria starts to compensate, but before the failure to cope with the vergence demand and the appearance of double or blurred images, the FD should reach the limits of Panum's areas (Kromeier et al., 2003). Therefore, measuring FD helps in assessing the phoria compensation status. Sheedy and Saladin (1978b) proposed using FD to assess phoria compensation. FD is measured using equipment with a central fusion lock. It provides a more accurate indication of the objective visual axis's alignment than without a central fusion lock (Lambooij, Fortuin, Ijsselsteijn, Evans & Heynderickx, 2011). It is considered the more realistic method. However, Otto, Kromeier, Bach and Kommerell (2008a) demonstrated that prism prescription, according to the FD, is not accurate. The authors demonstrated that, on average, the associated phoria measured with the Mallett Unit was shifted about 2 PD towards the eso direction. Therefore, there may be a need for a more precise method, which should include evaluation of stereopsis. Nevertheless, the current studies will measure and evaluate the role of FD in phoria decompensation diagnosis and management.

The most popular FD measurement instrument in the UK is the Mallett Unit (Karania & Evans, 2006). Its key component is the presence of peripheral and foveal fusion lock, which makes viewing conditions close to normal (O'Leary & Evans, 2006).

1.11. Vision Therapy (VT)

VT is one of the treatment options for decompensating Exo deviation at near, either alongside or instead of prism prescription. It is a non-surgical treatment for binocular vision disorders. VT include exercises using special equipment and computer vision therapy. The treatment can be office-based and/or home-based. There is a lack of an established treatment program. The published studies are not homogeneous regarding the therapy protocol, outcome measures, age of the participants, eligibility criteria, etc. (Alvarez et al., 2020).

The current practice in the author's clinic is to prescribe relieving prism in the case of a symptomatic decompensated exo phoria. VT is recommended as an in-office-based treatment with home-based reinforcement in such cases. Since diplopia may compromise a person's ability to function normally, read, study, work with a computer, or perform everyday tasks at home. Therefore, a prism is prescribed to enable normal visual functioning.

The effect of VT treatment is effective and contributes to a significant clinical improvement compared to placebo vision therapy/orthoptics (Scheiman et al., 2005). Despite the fact that there is a lack of consensus regarding the most appropriate VT treatment procedures, the effect of the treatment is well-proven (Aletaha, Daneshvar, Mosallaei, Bagheri & Khalili, 2018). Convergence Insufficiency Treatment Trial Study Group (2008) ran a study with 221 participants with CI who received home-based pencil push-ups or home-based computer vergence/accommodative therapy and pencil push-ups or office-based vergence/accommodative therapy with home reinforcement or office-based placebo therapy. The treatment duration was 12 weeks in all of the groups. After the treatment, the symptoms, according to the (Convergence Insufficiency Symptoms Survey (CISS) score for the office therapy group, were significantly lower than treatment in other groups. Moreover, the office-based therapy group demonstrated significantly greater improvement in the clinical performance of Positive Fusional Vergence (PFV) and Near Point of Convergence (NPC). The correlation between the clinical signs and the symptoms is discussed in Appendix 5.

Jang, Jang, Tai-Hyung and Moon (2017) conducted a study with 32 participants with symptomatic Convergence Insufficiency (CI) who underwent VT for 8 weeks. The

treatment was based on Scheiman and Wick's classification criteria (Scheiman & Wick, 2008). Scheiman et al. (2005) compared VT with pencil pushups and placebo VT as treatments for 46 adult symptomatic patients with CI. The participants were randomly divided into three groups, and they received 12 weeks of in-office VT, office-based placebo VT, or pencil push-ups at home. The authors measured the CISS, NPC and Positive Fusional Reserves (PFR) at near an outcome. The clinically significant improvements (NPC and PFR) were achieved only in the treatment groups but not in the placebo group. Although, the symptoms improved in all three groups (42% in office-based VT, 31% in office-based placebo VT, and 20% in home-based pencil push-ups). A later study published by Scheiman et al. (2010) confirms that office-based VT with home reinforcement contributes to a more rapid rate of improvement for clinical signs (NPC and PFV) than for symptoms. It is a more effective method than home-based pencil push-ups, computer vergence/accommodative therapy and pencil push-ups, or office-based placebo therapy with home reinforcement for a 12-week therapy. Tiwari et al. (2017) demonstrated the efficiency of in-office VT among computer users with CI. The VT treatment effect is longstanding (Westman & Liinamaa, 2012). "How do Different Treatments for the Vision Disorder, Convergence Insufficiency, Compare in Effectiveness" (2020) study confirms that office-based VT is more efficient than home-based pencil push-ups, home-based computer therapy, and the placebo treatment.

Several brain regions are associated with vergence eye movements (Widmer et al., 2018). Widmer et al. (2018) compared the changes in brain activation following office-based VT versus placebo therapy for CI using blood oxygenation level-dependent signals from functional magnetic resonance imaging (fMRI). Seven participants were randomly divided into two groups. One received placebo therapy, and the other received office-based vergence-accommodative therapy for 12 weeks. Baseline and outcome of fMRI scans. Positive fusional vergence was evaluated during outcome and baseline fMRI scans. The authors reported increased blood oxygen level-dependent response following VT in the occipital areas. The results suggest that VT may improve disparity processing for vergence and depth. Alvarez et al. (2010) demonstrated changes in three areas (frontal eye fields, posterior parietal cortex, and cerebellar vermis), which are associated with accommodation/convergence eye movements, in response to VT using magnetic resonance imaging among subjects with convergence insufficiency. The subjects suffered from CI and received an overall 6 hours at home

and 12 hours in-office VT. The authors reported an increase in brain activation during VT for CI post-therapy.

Even though the vast majority of evidence indicates the effectiveness of VT, some studies dispute this effectiveness. Wang & Kuwera (2022) conducted a literature review and found that VT is effective in the management of convergence insufficiency but cannot be recommended for the management of amblyopia, strabismus and learning disability in the paediatric population.

VT is an effective method for decompensating exophoria treatment. Patients respond to treatment at any age (Aziz, Cleary, Stewart & Weir, 2006; Evans, 2000). However, VT may be a less appropriate treatment option for older patients (Winn, Gilmartin, Sculfor & Bamford, 1994). Shin, Park, and Maples (2011) conducted a study with fifty-seven participants with symptomatic CI who were divided into treatment and control groups. The treatment group received 12 weeks of VT, and the control received no therapy. A one-year follow-up examination demonstrated that most participants maintained improved symptoms and clinical measures after VT.

VT is an effective treatment method for decompensating exo phoria. Although therapy requires time and is associated with material costs, many patients undergo treatment. The treatment results are expressed in relief from symptoms and achievement of normal optometric test results.

1.12. Current phoria decompensating treatment options

A few tests should be performed to diagnose the phoria compensation status. Combining those test results leads to a decision regarding the compensation status. Each test examines a different function of the binocular system. It is impossible to draw a conclusion based on just one test. Moreover, symptoms are also taken into account when diagnosing. The criteria or differentiating between compensated, decompensating and decompensated heterophoria is discussed in section 1.7. Cacho-Martínez, García-Muñoz and Ruiz-Cantero (2010) analysed the diagnostic criteria for non-strabismic binocular dysfunctions in the scientific literature published from 1986 to 2012. The authors found no consensus regarding diagnostic criteria. Since existing diagnostic methods do not make it possible to differentiate phoria compensation status, there is a need for a clinical tool that allows it.

There are a few decompensating exophoria treatment options. Relieving prism is the most common option for adult patients. There is no consensus regarding the prescription methods for relieving prism, but the most commonly used are Sheard's criterion, the motor approach, the FD method, and the sensory approach (Frantz, 1997).

The relieving prism is the minimum amount of prism that reduces the demand on the vergence system (and the heterophoria becomes compensated) but does not reduce the deviation to zero. The relieving prism is less than the dissociated phoria, and it is described as the aligning prism. Opinions differ significantly regarding the prism prescribing method. Some methods use the FR to calculate the amount of prism that should be prescribed according to a specific criterion (Sheard's criterion, Percival's criteria, Saladin's 1:1 rule). Other methods use the FD, the FD disparity curve slope, or the spherical manipulation to compensate for phoria.

The overarching approach is to prescribe a minimal amount of prism rather than full phoria correction so as not to create a prism dependence by the patient. If the patient becomes dependent on the prism, they will need to wear the prismatic correction all day long. A partial phoria correction should enable the patient not to use the glasses intermittently. Prism will help to cope with the deviation of the struggling binocular system rather than taking all the load. There is no need to make the patient more dependent on a prismatic correction than needed (Evans, 2007, chapter 6, page 105). Moreover, the higher the prism, the higher the lens aberration. This research attempts to calculate the minimal amount of prism that reduces the symptoms to a greater extent.

A prism is prescribed for decompensating exo in an attempt to reduce the required amount of the vergence response. The outcome of the prismatic treatment will be mainly based on alleviating symptoms (Rae, 2015).

1.12.1. The Motor Approach

A few tests should be performed to diagnose the phoria compensation status according to the motor approach**.**

1.12.1.1. The Cover Test

To diagnose phoria decompensation, the deviation angle needs to be measured using the Cover Test (CT), a commonly performed test in the clinic. This objective test measures the magnitude of phoria and differentiates phoria from tropia (Anderson, Manny, Cotter, Mitchell, and Irani, 2010). The practitioner observes the patient's eye movement while performing the test and measures the deviation using a prism. The practitioner does not rely on the patient's response. Because the test requires some subjectivity from the practitioner's observation rather than an eye tracker (eye-movement recorder), which is a totally objective measurement, CT may be referred to as a semi-objective test. However, from the clinical perspective, CT is seen as an objective test (Scheiman & Wick, 2002, chapter 1, page 6).

The phoria magnitude itself does not indicate the compensation status, as this value should be related to compensating fusional reserve. It is fundamental to measure the heterophoria, the magnitude of a deviation in the two visual axes' alignment while assessing the binocular functions. Many tests can be used to measure the deviation, such as CT, Von Graefe method, Maddox rod test, Maddox wing test, Thorington test, Howell near phoria card, etc. It is rational to choose a test that simulates natural viewing conditions, such as the CT. The CT is considered a "gold standard" test in many countries worldwide and is the first-choice test to measure the heterophoria angle. Most of the alternative methods are subjective, in which the amount of deviation is established according to what the patient says that he/she sees. On the other hand, the Cover test is an objective clinical test. The examiner assumes the heterophoria angle based on his observations without considering what the patient says (Mestre, Otero, Díaz-Doutón, Gautier, & Pujol, 2018; Johns, Manny, Fern, & Hu, (2004). Since the cover test is an objective test that provides reasonably accurate and repeatable results, CT will be used to evaluate the phoria angle in the current study.

1.12.1.2. Fusional Reserves (FR)

Fusional vergence amplitude demonstrates the oculomotor system's ability to maintain sensory fusion. Traditionally, this has been seen as a mechanism to prevent diplopia (Archer et al., 1986). A clinician should measure the patient's phoria and the vergence amplitude. This proportion is needed to draw a conclusion regarding the

compensation of a given phoria (Antona, Barrio, Barra, Gonzalez & Sanchez, 2008). Given the heterophoria is too large for the motor and sensory fusion to cope with, it causes a heterophoria to decompensate. The FR may vary depending on the patient's condition. For example, when a person is ill, tired, or doesn't get enough sleep, the fusional reserves may weaken.

1.12.1.3. Percival's criterion

Percival and Fox (1922) were the first to propose a criterion to differentiate the phoria compensation status based on the FR: Percival's criterion. According to Percival's criterion, the patient should operate in the middle third of his/her vergence range for heterophoria to remain compensated. If the patient has 20 prism diopter positive fusional reserves, he/she should have at least ten prism diopter negative fusional reserves to overcome the heterophoria (Conway, 2012). The formula for Percival's criterion is:

$$\text{Prism needed} = 1/3\ G - 2/3\ L$$

G – greater of the two lateral fusional reserves.

L – lesser of the two lateral fusional reserves.

The limitation of Percival's criterion is that it compares the positive to the negative fusional reserve without considering the patient's heterophoria (Percival & Fox, 1922). Sheedy and Saladin (1978a) conducted a study in which 77 students were divided into symptomatic and asymptomatic groups according to a questionnaire. They found that Percival's criterion showed better discrimination with eso deviation than with exo. A possible explanation for this is that the negative FR is passive. The concept of Percival's criterion is to achieve visual comfort by using the middle third of the vergence range, which puts the vergence in a more passive role. Another limitation is that the traditional criteria based on blur points were insufficient to diagnose the phoria compensation status. Therefore, the criteria were changed based on the break and recovery point, which gave a much more convincing result (Sheedy & Saladin, 1978b), and provided a better exo phoria decompensation discrimination. Currently, the Percival criterion is not used for exo deviation (Evans, 2001; Alrasheed et al., 2021); it was replaced by Saladin's 1:1 rule (Frantz, 1997). Because of that, this criterion was not tested in the current research.

1.12.1.4. Sheard's criterion

The calculation of Sheard's Criterion is also based on the FR (Sheard, 1930). According to Sheard's criterion, the compensating fusion vergence amplitude opposing the heterophoria should be at least twice the size of the deviation (Sheards, 1934). Sheard did not conduct clinical studies to determine the formula for calculating the prism. The fact that the compensating reserve should be twice as large as the deviation is the author's opinion and not the result of clinical studies. Sheard suggested that asthenopia and ocular symptoms may be present as a result of the inability of FR to cope with fusional demands. Sheard refers to the "Area of Comfort" as an outcome of prismatic correction. SPC was developed upon the symptom reduction using a uniform questionnaire in a double-blind study while incorporating stereoacuity improvement.

Sheard stated that the blur point of the FR should be considered in the calculation. If there is no blur point, a break point should be considered. For example, a patient with a 12-prism diopter exophoria should have at least 24 diopters of the positive fusional reserve to overcome his/her heterophoria. The formula for Sheard's criterion is:

Prism needed = 2/3 heterophoria – 1/3 (compensating fusional reserves)

Vergence system anomalies were considered to exist when the patient failed to meet this criterion, i.e., the value of Sheard's criterion was greater than zero.

There is no agreement regarding which point should be used in Sheard's criterion calculation: the blur point in fusional reserve, break or recovery. Moreover, measured fusional reserves depend highly on the test conditions. A large randomised controlled trial found prism prescribed in this way ineffective (Scheiman et al. 2005). The above agrees with Scheiman's and Wick's (2002) opinions, which stated that prisms based on Sheard's criterion are not likely effective.

Another limitation is that the blur point is used to calculate the criterion but is not always determined. In this case, the calculation is carried out according to the breaking point, which is higher (Sheard, 1930). Thus, the calculation turns out to be wrong. Moreover, as was said before, it can be considered only as a guideline (Gall & Wick, 2003). Because of that, the formula is appropriate neither for the diagnosis nor prism

prescribing. Moon, Kim and Yu (2020) examined one hundred eighty-four university students with ocular discomfort, evaluated Sheard's and Percival's criteria, and performed the Receiver Operating Characteristic (ROC) curve analysis of convergence insufficiency (CI) signs. The results showed that Sheard's criterion could be used as a screening tool combining Near Point of Convergence (NPC) tests to discriminate CI with exophoria at near from non-CI.

Another limitation is that Sheard's criterion is dichotomous, which means it can be met or not met (Myklebust, 2016). It means that the criterion does not make it possible to differentiate the phoria compensation level. The concept of Sheard's criterion is to oppose the compensating FR to the deviation. Myklebust and Riddell (2016) conducted a study with 82 participants comparing Sheard's criterion with "fusional stamina" (calculated by dividing Positive FR by two and then subtracting the phoria) as an alternative measure. The authors reported that Sheard's criterion runs the risk of missing potential binocular problems if the optometrist relies solely on this criterion, as 12.5% of participants failed to pass it.

Gall and Wick (2003) suggested that Percival's and Sheard's criteria can be considered only as a guideline since, in some cases, they do not reveal symptomatic patients. Moreover, there are no reliable clinical studies regarding the successful prescription of prismatic correction in the literature according to Percival's criterion for exo decompensated heterophoria. Sheedy and Saladin (1978a) stated that positive FR is a more active process than negative FR; Sheard's criterion is a much better-discriminating tool for exo but not for eso.

1.12.1.5. Relieving Prism Calculation According to Sheard's Criterion

In addition to the limitations of Sheard's criterion mentioned above, there is evidence that this criterion is not without criticism. Since there is no clinical justification for the formula proposed by Sheard, it can be considered the author's personal opinion. Moreover, the criterion was developed long before the equipment currently used was available. This indicates the need to reconsider the prism assignment method.

Scheiman et al. (2002) compared the prescription of base-in prism reading glasses effect according to Sheard's Criterion with placebo reading glasses. From this

perspective, the randomised clinical group consisted of 72 symptomatic (convergence insufficiency) participants. According to Sheard's Criterion, the prism reading glasses were no more effective than placebo reading glasses. The symptoms decrease in both groups (mean (SD) p = 0.33) was not significantly different (base-in prism glasses fell from 31.6 (10.4) to 16.5 (9.2) and placebo glasses from 28.4 (8.8) to 17.5 (12.3). Therefore, all results may be due to placebo effect. Moon et al. (2020) suggested that Sheard's criteria can only serve as a screening tool for decompensating heterophoria in conjunction with the NPC. It means that prism prescribing, according to Sheard's criterion, is not the optimal method, and this method should be strengthened further, which is the purpose of this study.

1.12.2. The Sensory Approach

The FD is one of the most popular methods for prescribing prisms among optometrists in the UK (O'Leary & Evans, 2003). It is also one of the UK's most popular heterophoria diagnostic methods and an indicator of phoria compensation (Frantz,1997; Grishmian &Thomas, 1974; Jainta & Jaschinski, 2002; Jenkins et al., 1989; Jenkins & Yekta, 1987; Mallett, 1964; Pickwell et al., 1991; Sheedy & Saladin, 1978a; Yekta et al., 1989).

There are two ways to calculate the relieving prism using the FD. The first is the amount of aligning prism needed to correct the fixation disparity and align the Nonius lines (the sensory FD approach). The second (the motor FD approach) is to build a Fixation Disparity Curve (FDC). A motor-based approach evaluation of FD is used in the USA, where the binocular system is stressed by known amounts of vergence demand using prisms. Then, the results are plotted on a curve (forced vergence fixation disparity curve). On the other hand, in English and German countries, an FD sensory-based approach is used. FD is analysed as a sensory adaptation to a minor misalignment of visual axes or a shift of correspondence within Panum's area (London & Crelier, 2006). There are two conflicting approaches to using FD; in the USA, FD is used as stability under prismatic stress, and the Mallett Unit is used in the UK as the 'resting' point.

The FD sensory prism prescribing approach refers to a prism prescribed according to the associated phoria or the Fixation Disparity (FD). The most common FD measuring device in the clinic is the Mallett Unit. According to Karania and Evans

(2006), 85% of optometrists in the UK use the Mallett Unit. Mallett Unit is a clinical test designed to detect the FD and measure the associated phoria in Prism Diopter (PD). The patient uses a polarising filter over their correction to dissociate the Nonius lines on the Mallett Unit. Each eye sees only one line, and both see the binocular target. These binocular targets contribute to the fusional lock. The prism amount that eliminates the misalignment of the Nonius lines refers to the associated phoria. This amount of prism refers to the FD (Conway et al., 2012) and is prescribed to the patient with heterophoria according to this method. The amount of associated phoria, 'aligning prism', is believed to correspond to the prismatic correction value prescribed to patients with decompensating exo phoria (Mallett, 1964).

The FD sensory approach was developed later than the FD motor approach and is used in certain countries. However, this method is subject to criticism that the test is carried out in abnormal viewing conditions, which induces artefacts and cannot be unambiguously recommended for prism prescribing (Otto et al., 2008b). Evidence shows that random-dot stereotest correlates to the FD (Jiménez, Olivares, Pérez-Ocón & del Barco, 2000).

1.12.2.1. Fixation Disparity Using Mallett Unit

Fixation Disparity can be described as limits of disparity vergence or the ability to cope with heterophoria - the objectively observed failure to cope with the vergence demand (Kromeier et al., 2003). The associated phoria (FD) is a small deviation angle, about five to ten minutes of arc (Sheedy, 1980). The smallest deviation angle that can be detected by an examiner using CT is about two PD (Fogt, Baughman & Good, 2000; Ludvigh, 19949). Since FD cannot be evaluated using the cover test, a particular instrument is needed to detect FD. Mallett suggested such a device in 1964 (Mallett,1964). The test has a central and peripheral fusional lock. The central "XOX" target plays the role of the central fusion lock, and the surrounding text plays the role of a peripheral fusion lock (Karania & Evans, 2006). Through a polarised filter, the patient sees one Nonius line above the "XOX" by his right eye and the other beneath the "XOX" target by his left eye. If the Nonius lines are displaced from one according to the other, a prism is placed to align the lines. The amount of the aligning prism refers to the associated phoria Karania & Evans, 2006). However, this test does not measure the fixation disparity; it only identifies the presence of a disparity by noticing the Nonius

markers' misalignment (Parmar, 2019). The Mallett unit fixation disparity test helps detect decompensated or decompensating heterophoria (O'Leary & Evans, 2003). The aligning prism can be used as a means of prism prescription (Section 1.12.2.2). It is still one of the most popular methods among optometrists in the United Kingdom.

1.12.2.2. Sensory-based approach as a clinical diagnosis method

FD may serve to differentiate the phoria compensation status by measuring the associated phoria using the Mallett Unit (Karania & Evans, 2006). FD is seen as a sensory adaptation to a slight displacement of the visual axes in the central Panum's area. This sensory adaptation extends to the periphery of Panum's fusional area (London & Crelier, 2006). This instrument provides an adequate fusional lock. The prism that neutralises the FD is called the associated phoria (Schroth, Prenat, Vlasak & Crelier, 2017) and is currently used for diagnosis and prism prescribing. Pickwell, Kaye and Jenkis (1991) investigated the relationship between associated phoria measured with Mallett and symptoms among 383 subjects, where 42% of the participants were symptomatic. The authors found that in the group under forty years, 30% of the symptomatic subjects had associated phoria of two prism diopters or more at near. It means that associated phoria can be helpful in detecting phoria decompensation at near. The prism prescribed in this method is the one that enables a stable alignment of the Nonius lines when the associated phoria is zero (Frantz, 1997). Payne et al. (1974) conducted a double-blind experiment with a small group of participants, prescribing prism according to the associated heterophoria, measured with the Mallett Unit. The authors concluded that associated phoria could be a clinical tool for assessing oculomotor balance.

Associated phoria is one of the currently used prism prescribing methods. Conway (2012) demonstrated a strong negative correlation between the BI aligning prism (associated exophoria measured with Mallett unit) and positive FR measured with the prism bar. Karania and Evans (2006) stated that associated phoria measured with the Mallett unit is a valuable tool for detecting symptomatic heterophoria at near. Jaschinski (2018) noted that the subjective measurements of FD obtained using the Mallett unit do not accurately reflect the objective criteria assessed with eye trackers. There were twelve subjects aged 20–29 years. This indicates that the associated phoria

measured with the Mallett unit is not suitable for prism prescribing. Moreover, Otto et al. (2008b) researched 20 participants to establish whether it is possible to prescribe a prism according to the dissociated or associated phoria. The authors compared a prism gained with the Mallett Unit and a “self-selected prism”, which was gained using liquid crystal shutter goggles displaying identical images to both eyes. The research concluded that a single test does not suffice to prescribe therapeutic prisms. This means that FD cannot be the basis for prism prescribing. O'Leary and Evans (2006) explored the effect of prescribing prisms according to the associated phoria using the Mallett unit on the dynamic visual function (the Wilkins Rate of Reading Test - WRRT) among 80 adult participants. For exophoria, a sensitivity of 67% was an aligning prism of 2D and above and a specificity of 79%, improving at the WRRT by at least 5%. The authors reported that FD is a valuable test for decompensated heterophoria, but its sensitivity and specificity are not precise enough to prescribe prism. The authors recommended combining FD results with symptoms and other tests, including fusional reserves. Since the clinically available FD tests do not provide natural viewing conditions, the FDC is unreliable for identifying symptomatic subjects (Kromeier et al., 2003). From the above, it can be concluded that the FD method is not accurate to prescribe relieving prism in practice.

The motor approach, as well as the sensory approach, cannot be considered a successful prescribing prism method because of the reasons mentioned above. However, there is a correlation between associated phoria and decompensating status. In light of the above, associative phoria by itself is not an adequate argument for prism prescribing. However, those methods are currently used in optometry practice to diagnose phoria compensation status and to prescribe prism. For this reason, it will be taken into account in this study.

1.12.2.3. Fixation Disparity Curve (FDC)

The FD evaluation strategy stresses the vergence systems by a known amount of prismatic demand and plots the results on a forced vergence fixation disparity curve. A fixation disparity curve (FDC) can be plotted to determine the amount of prism prescribed. An X-Y plot demonstrates how fixation disparity changes in response to a different value of relative vergence effort, which is induced using an additional amount of prism (Ngan, Gross & Despirito, 2005). The FDC was first proposed and classified

into four types by Ogle, Martens and Dyer (1967). Sheedy and Saladin (1978) reported the clinical relevance of the FDC. The pattern of the obtained curve was then analysed to make further therapeutic recommendations. Yekta et al. (1989) conducted a study with 189 adult participants who were divided into pre-presbyopic (up to 39 years of age) and presbyopic (40 years and over) groups to find the relationship between symptoms and the FDC. Subjects in each group were divided into symptomatic and asymptomatic. T-test showed no significant difference between two phoria means in both groups in presbyopes and pre-presbyopes ($p<0,001$) and the FD slope ($p<0,001$). It means that the FDC is not an indicator for phoria decompensation. On the other hand, Gall and Wick (2003) investigated eighty adult subjects (30 symptomatic and 50 asymptomatic) to investigate which optometric tests differentiate symptomatic from asymptomatic patients. The FDC showed no significant difference between the two groups.

A prism that is prescribed according to FDC flattens out the curve. With most binocular vision tests, differences in the design of trials mean that different instruments produce different results, which is true of fixation disparity curves (Ngan et al. 2005). Moreover, some studies concluded that the amount of prism prescribed using the FDC is not precise since it is not sensitive enough to differentiate the phoria compensation status, and it might be justified in single cases when a person has symptoms (Jainta & Jaschinski, 2002; Jaschinski, 2018). On the other hand, Momeni-Moghadam et al. (2013) demonstrated that the FDC slope is sensitive to symptomatic patients, which is consistent with the results obtained by Sheedy & Saladin (1978b). Sheedy & Saladin (1978b) and Mallett (1964) reported that fixation disparity is a good indicator of decompensated heterophoria compared to the heterophoria magnitude. However, these studies investigated the “subjective fixation disparity”, which does not allow for a precise prediction of the objective measures (Jaschinski, 2018). Since the FDC method is used less and less in modern optometry, it was not examined in this study.

1.12.3. Other Strategies

The most common decompensating phoria at near treatment methods are relieving prism and VT. However, despite the lack of adequate clinical trials, modifying the refractive error correction by adding over-minus is an alternative strategy that is underused in optometric practice. The amount of the over-minus correction is calculated according to the Accommodative-Convergence to Accommodation ratio (AC/A ratio).

The over-minus correction stimulates an extra accommodation response, which stimulates the convergence. A large amount of over-minus is most likely needed to impact convergence enough to compensate for the deviation. However, a low AC/A ratio is typically found with decompensating exophoria at near (Rae, 2015). Another limitation is the Amplitude of Accommodation of the subject, which should be enough to compensate for the spherical manipulation and allow for comfortable work at near.

Abri et al. (2021) examined one hundred sixty-three participants with intermittent exotropia for at least twelve months to evaluate the over-minus lens therapy effect on the angle of deviation. The authors found that 66.8% of participants achieved good controlled deviation angle or orthotropia after one year. The mean initial exo phoria was 24.7 ± 15.1 PD, which improved to 10.6 ± 4.2 PD with a median follow-up of 38 months (P = 0.02) with over-minus glasses. The research conclusion is that over-minus therapy can be an effective method to control exo phoria. Another study with a five-year follow-up was conducted by Rowe, Noonan, Freeman and DeBell (2009) to evaluate the overcorrecting minus lenses as a primary treatment option for intermittent distance exotropia in a prospective nonrandomised longitudinal cohort study with twenty-one patients. The treatment significantly reduced the angle of deviation (52% of the patients achieved a successful or good outcome). The studies of Caltrider and Jampolsky (1983) and Alizadeh et al. (2023) are in agreement with the studies mentioned before. Feng, Jiang, Bai, Li and Li (2021) found it useful to prescribe over minus of -2,50D combined with 4 PD base in prism.

Surgical intervention or chemodenervation may be considered in cases with a large deviation angle (Rae, 2015).

The treatment strategy mainly depends on the practitioner's practice, competence and education level. Optometrists, orthoptists, and ophthalmologists adhere to different methods (Rae, 2015).

1.13. A Gap in the Knowledge

One of the two most common orthoptic problems is decompensated exophoria at near (Montés-Micó, 2001; Clark & Clark, 2015; García-Muñoz, Carbonell-Bonete, Cantó-Cerdán & Cacho-Martínez, 2016; Hashemi et al., 2017). However, there is a lack of proper epidemiological studies on the prevalence of decompensating phoria (Cacho-

Martínez, 2010). There is no definite agreement regarding the decompensating criteria, how to diagnose decompensating phoria, which clinical tests should be performed, and how exactly they should be executed. Moreover, there is no agreement on comparing the results of different tests to evaluate the phoria compensation level. There are a few prism-prescribing criteria in current use. However, none of those management methods has a full justification. Cacho-Martínez (2010) analysed the diagnostic criteria for non-strabismic binocular dysfunctions in the scientific literature published from 1986 to 2012. The authors found that there is no consensus regarding diagnostic criteria. Since existing diagnostic methods do not make it possible to differentiate phoria compensation status, there is a need for a clinical tool that allows it.

The research addresses the lack of an exact diagnostic technique for phoria compensation status and clear management recommendations. It introduces a novel approach, incorporating stereopsis measurement. The study aims to establish new, clinically justified and objective phoria compensation status criteria and prism prescribing method. The new prism prescribing criterion will be based on the use of currently available global stereotests. The study's comprehensive investigation of the subject's binocular system functions will enable more accurate phoria compensation status diagnostics in the clinic.

1.14. The purpose of this study

Prisms are commonly prescribed for binocular dysfunction. However, the literature lacks consensus on the prism prescribing methods and the appropriate prism prescribing practices. There is a dearth of proper clinical trials and an insufficient amount of published double-blind, placebo-controlled clinical studies regarding the prism prescribing methodology. Notably, there is a limited number of properly performed studies investigating the effect of relieving prism in adult patients with decompensating exo phoria. Most available studies were conducted in paediatric populations with a limited sample size and lack of a control group; they were performed non-randomised and with a short follow-up period (Stavis et al., 2002).

Heterophoria treatment options currently used in optometry are usually derived from the fixation disparity (FD) and fusional reserve (FR) methods. Both methods have their

weaknesses (discussed in section 1.12). Prescribing prism via Fusional Reserves for patients with exophoria depends upon the application of Sheard's criterion, which was developed in early 1930. There is no agreement on which point (blur or break) the prisms should be calculated (Sheard, 1934). Moreover, this method was long before the clinical availability of modern stereotests, especially the TNO test developed from experimental work in the 1960s. The suggestion that the TNO stereotests may better detect decompensating exophoria means that Sheard's criterion (and others in use, such as Percival's criterion and the 1:1 rule) may suffer from a lack of accuracy or precision, as the clinical information they were developed around may be insufficient and not convincing enough. The above suggests that reviewing FR according to local and global stereoacuity might help develop more precise prism prescribing criteria. This PhD project aims to expand on a previously unpublished pilot study (Rinsky, 2017) in several ways. Firstly, methodology improvement subsequently recruited a more significant patient population. Finally, to validate any new criteria compared to the current one, prisms will be prescribed to the participants randomly and double-blindly.

For the purpose of this thesis, the "Stereo Prism Criterion" will be called SPC.

1.15. Conclusion

A PubMed search has been done on Sheard's Criterion. A limited number of recent publications have been found. A literal review of a textbook shows that research on Sheard's Criterion is limited, and there is no convincing confirmation of the formula used in the criterion. The suggestion made by Sheard in 1930 that the positive fusional reserves should be twice the exophoria was made in the absence of clinical evidence, which is the author's opinion, and it is still not a clinically proven formula. One of the authors of this thesis, Professor Fergal Ennis, noticed that a student group received a relieving prism prescribed according to Sheard's Criterion. There was evidence that the stereoacuity was declining, and the students suffered from visual fatigue in this group. He also noticed in teaching clinics that the selective decline of the stereoacuity measured with TNO is associated with visual fatigue and heterophoria decompensation. The author has noticed that in her practice, the prism prescribed according to Sheard's Criterion does not sufficiently relieve symptoms. Her experience using Sheard's Criterion was that the amount of prism had to be elevated to gain better symptom relief. Moreover, the pilot study (Rinsky, 2017) confirmed that the decrease in TNO

stereoacuity is associated with the level of decompensation of exophoria. The reason for that may be that the near visual task has increased over the last years. Nowadays, we have devices such as notebooks. Tablets and smartphones were unavailable in 1930. The visual demand has increased over the years. Sheard's Criterion might have been appropriate in 1930 when we had no mobile phones and computers, but maybe it is not appropriate nowadays in the modern world.

More recent research has been done on the FD than on Sheard's Criterion, which provides evidence of its effectiveness despite the fact that Ogle's original work was carried out in the 60s of the last century. Bruce Evans and other researchers have worked on FD as a criterion for prescribing prisms and on its effectiveness. Still, the results are not convincing that FD can be used to prescribe prisms in all one hundred per cent of the patients with decompensating exophoria at near. Thereby, the criterion for reliving prism prescribing for decompensating exophoria at near is not clear. This research attempts to establish this criterion using the TNO stereotest. The assumption was that TNO is more sensitive to decompensating phoria; stereoacuity measured with TNO declines more rapidly than with Titmus and Randot stereotests. Because of that, TNO was chosen as a test to determine which prism should be prescribed. This study investigated the role of stereoacuity in assessing the level of exophoria decompensation, calculating the amount of prism prescribed, and comparing it to the other two commonly used prism-prescribing methods.

2. Validation of modified CISS with the Normal Participants Group

2.1. Introduction

In this research, a modified CISS was applied to evaluate the severity of the symptoms. The participants were provided with prismatic correction, which reduced the symptoms. The prism was prescribed according to Sheard's Criterion, the SPC, and the FD method in two separate experiments. The modified CISS questionnaire was filled in at the baseline, with no prismatic correction, and one and a half months after the patients were using the glasses with Fresnel prism.

The question of this experiment was whether the prism provided by the SPC alleviates symptoms and brings the symptoms to a normal value or whether the FD or Sheard's methods are sufficient to relieve symptoms. In order to answer those questions, a group of twenty-four participants with normal binocular vision were recounted to this experiment. The normal participants were asked to fill in the modified CISS questionnaire to compare the mean to the questionnaires of the symptomatic participants filled in after using a prismatic correction prescribed according to the SPC, Sheard's Criterion and the FD method. The normal group questionnaire mean was considered to be a normal symptom value. The hypothesis was that the prism prescribed according to FD and according to Sheard's Criterion was insufficient to relieve symptoms and bring them to a normal value, and SPC had a better performance.

2.2. Methodology

2.2.1. The Participants

Twenty-four participants were recruited for this experiment. The participants had normal binocular vision and underwent a complete eye examination. They were asked to fill in a modified CISS questionnaire. A mean modified CISS questionnaire with

standard deviation was calculated. Participants with a refractive error had been using their optical correction for at least six months prior to the experiment.

2.2.2. The Modified CISS Normal Value Establishment

This group of participants underwent one appointment, which included the next examination: History and symptoms, Entrance Tests, Refraction, Binocular Vision Examinations, and Near Tests. The methodology was the same as described in Chapter 3 and according to the Protocol (Section 3.9). The other tests that were held were:

- CT;
- FD;
- VF;
- Frisby;
- Titmus;
- TNO;
- TNO Trombone;

The methodology was the same as described in Chapter 3.

2.3. Results

Twenty-four participants were recruited for this experiment. The mean age of the participants was 39.2 ± 6.49 years old. Of the 24 subjects, 12 (50 %) were females, and 12 (50 %) were males. All 24 subjects underwent all the examinations described in Chapter 3. All participants had normal binocular vision according to the decompensation criteria discussed in section 1.7.

The mean of the binocularly ‘normal group‘ of the modified CISS questionnaire was compared with the mean of the modified CISS questionnaire of patients who were using the prismatic correction prescribed according to the SPC versus Sheard’s Criterion (Chapter 4) and according to the FD (Chapters 5).

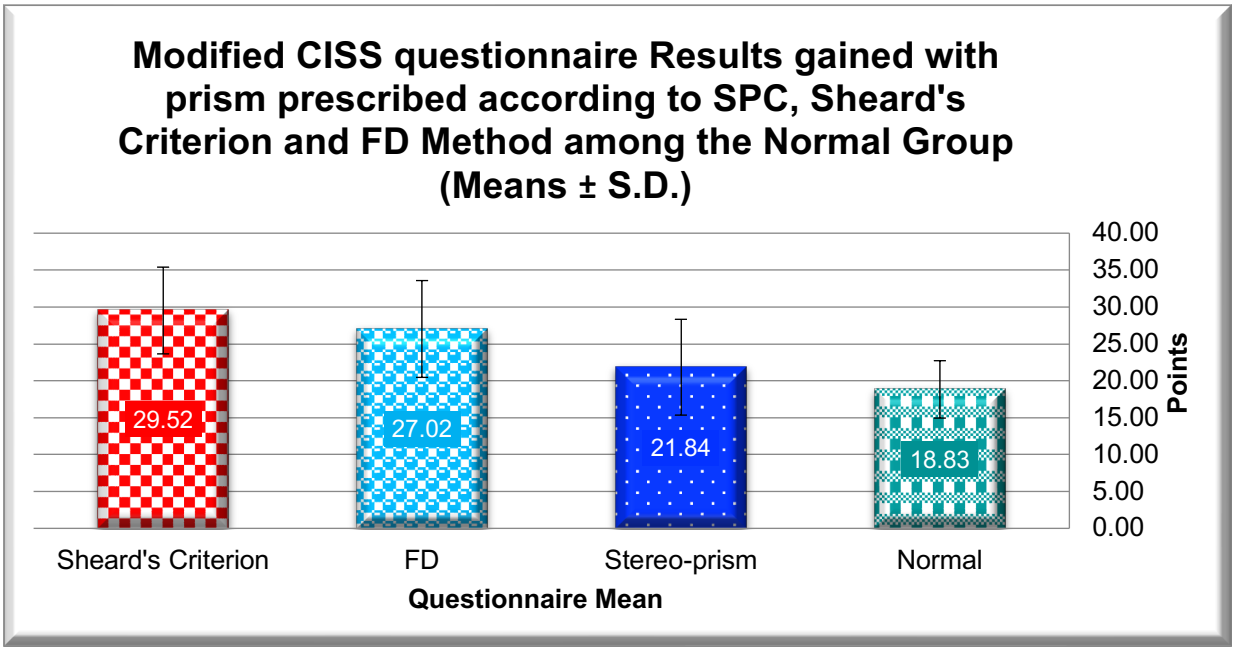


Figure 1: *The graph shows that the symptoms reached the mean of the binocularly 'normal group' level of (18.83, ±3.89) with the SPC (21.84, ±6.49) with $p<0.05$, but not with the FD method (27.02, ±6.63) and not with Sheard's Criterion (29.52, ±5.88) and where $p>0.05$. The error bars represent the Standard Deviation of the mean.*

Figure 1 demonstrates the mean modified CISS questionnaire for the participants with normal binocular system recruited for the Validation Experiment (18.83, ± 3.89) was not significantly different from the modified CISS gained with SPC in Sheard's experiment (Chapter 4). SPC provided significantly greater symptom relief compared to FD (27.02, ±6.63) (Chapter 5) and Sheard's Criterion (29.52, ±5.88) (Chapter 4).

A comparison between the modified CISS questionnaire's means was performed using the Repeated Measures ANOVA test. ANOVA showed a statistically significant difference with a very low p-value ($p<0.001$). The value of the test statistics was $F=28.806$ with a degree of freedom 3. A Tukey post-hoc test was performed to determine the significant difference between each test. The Tukey test showed no significant difference ($p=0.162$) between the Normal group and the SPC and between Sheard's and FD ($p=0.120$). The test showed a significant difference ($p<0.001$) between the Normal group and FD, as well as the Normal group and Sheard's ($p<0.001$). SPC was different from Sheard's and from FD ($p<0.001$).

2.4. Discussion

This experiment determined a modified CISS questionnaire mean value of a normal group (18.83, ± 3.89). This value was compared with the modified CISS questionnaire values obtained after applying prismatic correction prescribed according to the SPC, Sheard's Criterion and the FD method. Both commonly used relieving prism prescribing methods, Sheard's Criterion and the FD method, have been shown to reduce symptoms, but the mean symptom value was significantly higher than normal. On the other hand, the SPC has shown that it reduces the symptoms to be virtually normal.

The original CISS study established a score of ≥ 16 as the pass/fail point for diagnosing CI. Borsting et al. (2003) suggested that this score was valid. However, Bade et al. (2013) demonstrated less convincing results, stating that an association between the level of symptoms and the severity of the clinical signs is absent. The above studies were conducted among children, and the current study was conducted among adults. This may be why the participants reached a level of modified CISS questionnaire of 21.84, ±6.49 with the SPC, which was above the established CISS score of 16 points. On the other hand, Borsting et al. (2003) claimed that CISS is a valid instrument to apply among children, using a score of ≥ 16 for the children population and a score of ≥ 21 for adults (Rouse et al., 2004). Moreover, the authors claimed that further studies are needed to evaluate the CISS score in adults. A double-masked longitudinal randomised clinical trial conducted by Alvarez et al. (2020) investigated the change in symptoms and clinical signs after office-based VT or office-based placebo therapy among fifty young adults with symptomatic CI. The authors demonstrated that the group that received VT, NPC, and FR improved. However, the CISS improved to a comparable extent in the VT and placebo groups, with p=0.56. This means that CISS was a poor CI symptom indicator in this study. Thus, the score of 21.84, ±6.49 gained with the SPC can be considered to be virtually normal and applicable to the adult population that participated in this study.

Horwood, Toor, and Riddell (2014) conducted a study among 167 university students, using a cut-off CISS score of ≥ 21 to diagnose 'significant' symptoms. Scheiman et al. (2020) conducted a systematic review and network meta-analysis to assess the effectiveness of non-surgical CI treatment. The authors stated the primary

outcome of treatment to be CISS is normal (< 16) and an improvement of ≥ 10 points. Borsting et al. (2003) are in agreement with the previous conclusion that the improvement of the CISS by more than 10 points can be considered clinically meaningful. SPC improved the modified CISS by 20.04 in Sheard's experiment (Chapter 4) and by 18.92 in the FD experiment (Chapter 5), which is higher than 10 points (Figure 18). This means that the improvement was meaningful.

2.5. Conclusion

The SPC relieving prism contributed to a virtually normal symptom level, which did not happen with the FD method and Sheard's Criterion. In the context of symptom relief, the SPC was beneficial over Sheard's Criterion and FD method.

This research showed an improvement in symptom level from 42± 6.99 to 21.84, ±6.49 with the prism prescribed according to the SPC. This value is very close to a score that was suggested to be normal for adults, which is ≥ 21 in the literature (Section 6.4). Moreover, the improvement was higher than 10 points, which was considered to be significant according to studies discussed previously (Section 6.4). Furthermore, most of the normal participants who were included in this experiment were parents of children who underwent VT in the author's clinic. Thus, they had a family history of binocular vision abnormalities and maybe had a hereditary component. This group did not include a geriatric population as well. This may be the potential bias of the methodology and may not represent the adult population as a whole.

Considering the above and taking into account the normal value of symptoms determined by this experiment, the symptom level of 21.84, ±6.49 that was reached can be considered a virtually normal symptom level, which was gained with the SPC prism.

3. Materials and Methods

3.1. Ethics

The Research Ethics Audit Committee at the University of Hertfordshire, School of Optometry and Vision Sciences, approved this research and all included test procedures. The ethical approval was received on November 11th, 2022, with a protocol number of cLMS/PGR/UH/04813. All aspects of the study were concordant with the tenets of the Helsinki Declaration.

All participants were thoroughly informed about the purpose of the research and the possible risks and hazards, and informed consent (Appendix 1a, 1b) was obtained from all participants before testing.

3.2. Participants recruitment

The author is a practising optometrist who specialises in binocular vision disorders. She has her own optometry clinic where she sees patients. The vast majority of the author's patients have binocular vision disorders.

The author prescribes prismatic correction as an everyday practice and provides Vision Therapy (VT) if appropriate. The author also works with preschool children for about fifty per cent of her patients. The other fifty per cent are adults. Most adult patients visit the clinic once a year for a follow-up appointment. For this study, the author recruited participants from her private practice. From March to August 2020, 456 patients visited the author’s clinic. 240 patients were adults with binocular vision disorders who were prescribed prism correction, spherical manipulation, or/and visual therapy.

The total number of participants whose data were analysed was one hundred fifty (69 for “The Relieving Prism Prescribing, According to Sheard’s versus the SPC” (Chapter 4), 51 for “The Relieving Prism Prescribing According to FD versus the SPC” (Chapter 5), 24 for “Validation of modified CISS with the Normal Participants Group” (Chapter 2) and 6 for “Decompensating Heterophoria with Normal Stereoacuity – Refining the TNO” (Chapter 6).

3.3. Inclusion and exclusion criteria

Since a child reaches normal results in stereo acuity test scores by age 7 (Cooper, Feldman & Medlin, 1979) and both near and distance stereo acuity tend to decline with age (Garnham & Sloper, 2006), patients over the age of 18 and under age of 65 were included in the study. The inclusion and exclusion criteria are according to Table 2. The tests were performed according to the standard approach described in Pickwell's Binocular Vision Anomalies by Evans, B. J. W. (2007, chapter 3) and Binocular Vision and Ocular Motility: Theory and Management of Strabismus 6th Edition by Von Noorden and Campos (2001).

The inclusion and exclusion criteria are mentioned in Table 3.

Table 3: The inclusion and exclusion criteria	
Inclusion criteria	Exclusion criteria
Myopia, hyperopia, astigmatism and anisometropia (spherical equivalent) lower or equal to -6.00, +6.00 and 1.50, 1.50 dioptres, respectively*	Myopia, hyperopia, astigmatism and anisometropia (spherical equivalent) higher than -6.00, +6.00 and 1.50, 1.50 dioptres, respectively*
No history of significant eye trauma	History of significant eye trauma
Absence of significant retinal diseases, head injury, neurological disorders, or developmental delays.	Presence of significant retinal diseases, head injury or neurological disorders or developmental delays. Strabismus. History of strabismus surgery, patching, VT. No early (up to 10 years of age) onset of binocular vision disorder. Decompensating eso deviation.
Age 18-65	Age under 18 or over 65
Decompensating exo phoria at near (according to discussed in section 1.7)	Normal binocular vision*
Reduced stereoacuity on one of the stereotests (lower than 40 SOA on any stereotest used in this research)**	Normal stereopsis (equal to or better than 40 SOA on any stereotest used in this research)

Table 3: *The criteria for inclusion and exclusion for this research. * Normal binocular vision was considered according to Table 4. *This study considered the level of symptoms as one of the major decompensating heterophoria treatment outcomes. Since in other researches that deal with symptom questionnaires, the ametropia of ±6.00DS inclusion/exclusion was chosen as a cut-off, in the current research, the ±6.00DS was an inclusion/exclusion criterion in the Convergence Insufficiency Treatment Trial Study Group. (2008), a refractive error (based on cycloplegic refraction) of myopia ≥6.00 DS was a cut-off; in the Bade et al. (2013) study, the myopia of 6.00*

DS was cut-off, and in Borsting et al. (2009) research myopia of 6.00Ds sphere (in any meridian) was cut-off.

*** The inclusion criterion of 40 SOA on any of the stereotests means that in a TNO stereotest with no 40 SOA target, the inclusion criterion was to pass the 30 SOA target.*

All tests were chosen based on the author's regular practice and the available equipment.

The expected values of binocular vision testing are mentioned in Table 4.

Table 4: Expected Values of Binocular Vision Testing			
Test	Expected Findings		SD
Cover Test			
Distance		1 exo	±2 PD
Near		3 exo	±3 PD
Distance Lateral Phoria		1 exo	±2 PD
Near Lateral Phoria		3 exo	±3 PD
W4Dot		Fusion	
Schober test		Fusion	
AC/A		4/1	±2 PD
Step Vergence testing			
Base Out (distance)	Break	11 PD	±7 PD
	Recovery	7 PD	±2 PD
Base In (distance)	Break	7 PD	±3 PD
	Recovery	4 PD	±2 PD
Base Out (near)	Break	19 PD	±9 PD
	Recovery	14 PD	±7 PD
Base In (near)	Break	13 PD	±6 PD
	Recovery	10 PD	±5 PD
Fixation Disparity at distance (using Distance FD Unit)			0 PD
Fixation Disparity at near (using Mallett Unit)			0 PD
Stereoacuity (using Frisby, Titmus, Randot, TNO*)		40 SOA on one of the tests	
Vergence testing facility	15 CPM		±3 CPM
Near Point of Convergence (accommodative)	Break	5 cm	±2.5 cm
	Recovery	7 cm	±4 cm
Amplitude of Accommodation (push-Up test)		18-1/3 age	
Accommodation Response		Lag ≤ 0.75 D	

Table 3: *Expected Values of Binocular Vision Testing taken from Scheiman and Wick (2002). *30 SOA for TNO.*

The normal stereoacuity threshold was forty seconds of arc at one of the stereotests applied in this research (Frisby, Titmus, Randot and TNO). Stereoacuity below forty seconds of arc was considered to be reduced. Carlson and Kurtz (2004) have reported that the expected findings of stereoacuity are 20 seconds of arc. On the other hand, Lee and Koo (2005) applied a standard of stereopsis in their research of 50 seconds. Birch et al. (2008) noted that stereo acuity tends to improve from 100 SOA at three years of age to 60 seconds at five years, reaching 40 seconds at age 7. In the present study, the stereoacuity of 40 SOA was considered normal.

The participants were tested individually and examined according to the protocol on each appointment.

3.4. The First Appointment

In this research, the participants were asked to read the questionnaire themselves and fill it in themselves instead of having the clinician read it to them. This was the only difference (modification) from the original CISS. The modification was done to gain higher objectivity so that the researcher could not in any way influence the questionnaire's result.

At the first appointment, the participants underwent a full optometry examination. The appointment lasted up to two hours. An optical correction was prescribed, and the participant was supplied with it. The next tests were performed:

- The modified CISS questionnaire* _____;
- History and Symptoms;
- Distance VAs OD_____ OS _____ using Snellen** numbers chart at 6 meters and in 500-600 lx illumination without optical correction;
- Near VAs OD_____ OS _____ using Jaeger numbers chart at 40 centimetres and in 500-600 lx illumination;
- Pupils reactions _____;
- Motility _____;
- Slit lamp examination (Bio-microscopy) OD_____ OS_____;
- Direct ophthalmoscopy OD_____ OS_____;
- Objective refraction OD_____OS_____;

- Keratometry OD_____OS_____;
- Subjective Refraction was performed, and the results were written down in Table 5;
- Direct ophthalmoscopy.

* The modified CISS had 15 questions ranging from 0 (asymptomatic) to 60 (most symptomatic).
**The LogMAR visual acuity chart has been shown to provide more accurate results than the Snellen chart (Bailey & Lovie, (1976). However, since the Snellen chart is much more widely used among local optometrists than LogMar, Snellen's visual acuity was used in this research. Since VA was not an outcome measurement of the research, the measurement method did not affect the results. It was merely used as a screening test for inclusion purposes.

A symptom-based questionnaire was proposed to quantitatively measure the CI symptoms (Borsting et al., 2003). It was applied by Horwood, Toor and Riddell (2014), who conducted a CISS. The researchers found a high false-positive rate and a poor sensitivity to CI, and their questionnaire is not recommended as a CI screening tool. On the other hand, Borsting et al. (2003) conducted research to assess the validity of the CISS. To assess the repeatability of the CISS results, the questionnaire was filled in twice by participants with CI, and the results were compared with scores from participants with normal binocular vision. Borsting et al. (2003) demonstrated that participants with normal binocular vision showed a significantly lower CISS symptom score than participants with CI. The authors claimed that the questionnaire is a valid instrument CI to be used as a primary outcome measurement.

Pang, Teitelbaum and Krall (2012) also demonstrated in their study with twenty-nine participants that the CISS score improved with relieving prism, and the difference was statistically significant. On the other hand, Clark and Clark (2015) ran a prospective, randomised survey in which children 9–18 years of age with normal binocular vision participated. The authors compared the CISS means within two groups. One group filled in the questionnaire regarding reading, and the other regarding the participant's favourite close work. Using a smartphone was the most frequently chosen favourite near-vision activity. The CISS was modified. The questionnaire in one group was regarding reading, and the other group was regarding their favourite activity. The

questionnaire scores significantly overestimated near vision symptoms regarding reading, which were almost double those caused by favourite near visual activity and were close to the proposed cut-off score for Convergence Insufficiency (CI) diagnosis. The authors claimed that if their modified reading questionnaire had been used as a CI screening tool, about 40 per cent of the participants with normal binocular vision would have been misidentified CI and mislabelled as having CI. In another study by Rouse et al. (2004), the validity and reliability of CISS were evaluated. The questionnaire scores of forty-six adults with symptomatic CI were significantly higher than those of forty-six participants with normal binocular vision.

In support of the previous experiment with one hundred participants, Clark and Clark (2015) provided evidence that CISS was significantly overestimated. The participants were asked to read or to do their favourite nearby activity. After the visual activity, the participants filled in the questionnaire. The group that was doing their favourite near activity instead of reading got a modified survey (for example, where the word “reading” was changed to “favourite activity”). Since participants with normal binocular vision were recruited, using a questionnaire designed specifically for patients with an abnormal binocular visual system is questionable. Bade et al. (2013) showed a low correlation between the clinical signs (measured in clinical trials) severity and their level of symptoms using the CISS among symptomatic CI children.

Despite the limitations of the CISS mentioned above, this questionnaire was used in this study because there is no better alternative. CISS is still clinically used, and no better alternative has been proposed that the author is aware of. This study achieved statistically significant results using the CISS.

The protocol sheets for slit lamp and direct ophthalmoscopy examination are present in Appendix 3.

Table 5: Subjective Refraction Results Table								
	Sph	Cyl	ax	Add	Prism	Base	VA- D	VA- N
OD								
OS								

Table 5: *The Subjective Refraction Results Table.*

The Binocular Vision Examinations were carried out according to Table 6.

Table 6: Binocular Vision Assessment	
W4Dot	
Schober	
Distance FD	
Distance Vergence Facility (using flipper 12BO/3BI the fixation target was an optotype two lines larger than the participants near VA in the poorer-seeing eye)	
Distance CT (using prism-bar, the fixation target was an optotype two)	
Near CT (using prism-bar, the fixation target was an optotype two)	
Near FD (using Mallett Unit Tianle NV-100)	
Near Vergence Facility (using flipper 12BO/3BI the fixation target was an optotype two lines larger than the participants near VA in the poorer-seeing eye)	
AA (using RAF rule, with a fixation target an optotype two lines larger than the participants near VA)	RE LE
NRA/PRA	
Frisby/ Titmus/ Randot /TNO/TNO Trombone (from 80 cm)	
NPC (the fixation target was an optotype two lines larger than the participants near VA in the poorer-seeing eye)	

Table 6: *Binocular Vision assessment tests.*

The stereotests that were used are:

- Frisby Stereotests (Frisby Near Stereotest 3 plates), Oxfordshire, UK;
- Titmus Stereotest (Original Stereo Fly Stereotest), Stereo Optical Company INC, Chicago, USA;
- Random Dot Stereotest (Stereotest – Randot Including LEA Symbols), Randot and 2007 with Lea Symbols test. (Stereo Optical Company INC, Chicago, USA);
- TNO version fifteenth edition, Lameris Ootech, Ede, Holand.

PFR and NFR were measured using a prism bar (the fixation target was an optotype two lines larger than the participants near VA in the poorer-seeing eye), according to Table 6.

The classic method for FR measurement is to measure three points: the blur, break and recovery. In this research, FR is being measured by adding a fourth point, and for the purpose of this thesis, this point will be called a “Something Point”. Rather

than reporting those three points, an additional point was added before the blur. This is the point, while the Base Out prism was gradually added, when the participant felt any different feeling for the first time, like discomfort, pain, strain, fatigue, effort, etc., before the target became blurred.

The exact measurement methodology of the Something point is presented in Appendix 3 and discussed in Chapter 3.

Table 7: Fusional Reserves		
Something (the patient's word) The feeling _____ (FR after 30 seconds)		
blur	breaking	recovery

Table 7: *Fusional Reserves assessment tests.*

PFR and NFR using prism-bar (the fixation target was an optotype two lines larger than the participant's near VA in the poorer seeing eye).

3.4.1. The examination

The examination with the following conditions:

- The examination was performed using a unit table Huvitz HRT-7000 (Huvitz, Anyang, Republic of Korea) and a digital chart projector HCP-7000 (Huvitz, Anyang, Republic of Korea) at a 6 m. distance and in 500-600 lx illumination;
- The objective refraction was carried out using auto-ref-keratometer Visionix VX 110 or Huvitz HRT-7000(A) (Huvitz, Anyang, Republic of Korea);
- The subjective distance refraction using manual phoropter Reichert Ultramatic RX Master Phoroptor (Reichert, Inc., NY, USA);
- Distance monocular and binocular Visual Acuity using Snellen numbers chart at 6 meters and in 500-600 lx illumination with correction;
- All the near examinations were performed at a 40 cm. distance;
- All the near tests were performed using a trial frame with a full optical correction using a trial frame and an adjusted interpupillary distance;

- The prism bar used in this study had the next steps 1, 2, 4–20 in 2D steps and 25–40 in 5D steps. It was held before the participant's right eye at a 15 mm. distance;
- All the tests were performed in an optometry room. A separate room 18 square meters with all the above equipment;
- An authorised optometrist performed all the tests while the second authorised optometrist, who acted as an assistant, recorded the test results.

See Appendix 3 for the full protocol and test methodology.

3.5. The Second Appointment

The second appointment was held four to six weeks (± 3 days) later and took up to forty-five minutes. The participants were divided into two groups: a "Stereopsis compromised" (SC) group and a "Stereopsis-Normal" (SN) group.

3.5.1. Group 1 - stereoacuity is compromised (SC)

Group 1 included participants with decompensating heterophoria with compromised stereoacuity (i.e. > 40 SOA).

3.5.1.1. SPC calculation methods

Two values of compensating prisms were calculated at this appointment:

- One prism, according to the currently used Sheard's Criterion: ⅔ (exo phoria) - ⅓ positive fusional reserves blur point.
- The other prism was calculated according to the newly developed criterion (SPC): the minimal prism that provides the maximum stereoacuity on the TNO test.

The typical way for TNO measurement is for the subject to provide a correct answer for both figures of the same stereoacuity. Each figure allows a subject to guess the correct answer randomly, with a chance of 1 in 4 or 25%. However, a subject needs to pass both figures. The chance to randomly guess both figures the correct answer is one

out of sixteen or 6.25%. In Frisby and Titmus tests, the subject has to provide one answer out of four, meaning the chance to guess the correct answer is 25%. In Randot, the chance to guess is 33.33% (one out of three). The method for measuring stereoscopic vision using the TNO was changed to equalise the chances of randomly guessing the target in the TNO test with other tests (except Randot). The participant passed the test in this research, providing at least one correct answer.

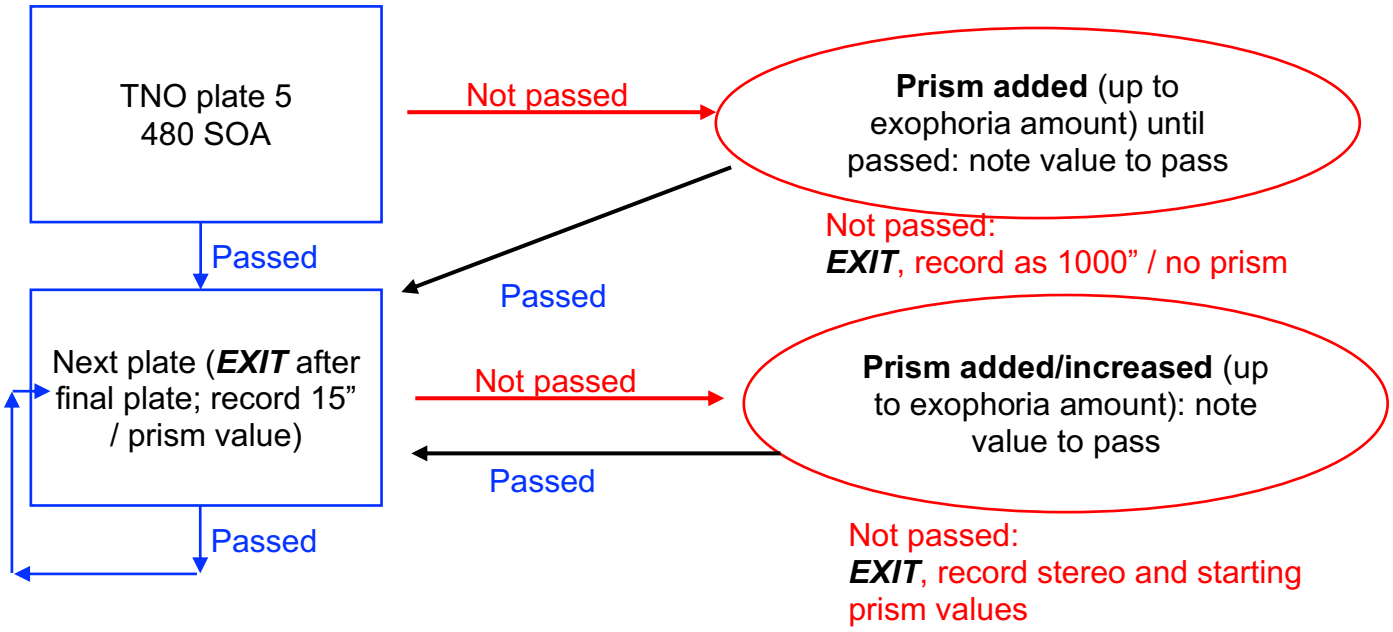
The participant wore the Red and Green anaglyphic filters over his/her optical correction if needed; the TNO booklet was open and folded so that only the participant could see Plate 5 (480 and 240 SOA). The participant was informed that there were four figures of a disc with a sector missing, and he/she was asked to identify the direction of the missing sector ("What is the direction of the missing sector on the next figures starting from the top left"). If the participant successfully completed the task (gave a correct answer for one or both targets with the same disparity), the booklet was opened and folded so that the participant could see only Plate 6 (120 and 60 SOA) and the instructions were repeated. If the participant successfully completed the task (gave a correct answer for one or both targets with the same disparity), the booklet was opened and folded so that the participant could see only Plate 7 (30 and 15 SOA) and the instructions were repeated.

If on any level of stereo, the participant failed to give an answer within 15 seconds, or the answer was wrong for both figures of the same stereoacuity, a prism bar was placed base-in in front of the right eye with its minimal prism amount, and the current plate was re-shown. If the participant passed the test, the procedure was repeated, with the next target being shown; if not, the amount of prism was increased. If, with an increased prism, the participant failed to give a correct answer, the prism was increased to the next prism step on the prism bar, and the measurement on the latest plate was repeated. The measurement was repeated until the prism bar reached the value equal to the heterophoria of the participant or until the participant gave the correct answer to the highest stereoacuity (lowest disparity), i.e. 15 SOA that exists in the TNO test. If, for example, the participant was looking at a plate with a disparity of 120 SOA with 6 Base In (BI) prism and gave a correct answer, he/she was shown the next plate with 60 SOA disparity. If he/she failed to give a correct answer within 15 seconds or gave a wrong answer, the prism was increased to 8 BI, and the measurement was repeated. If the participant failed the test, the prism was increased to the next level (10

BI). If with 10 BI, the participant filed the test. The prism was increased step by step in the same manner until it reached an amount equal to the participant's heterophoria. If with the prism amount that was equal to the participant's exophoria, in this case, the participant could not give a correct answer, the relieving prism, according to the SPC, was considered to be 6 BI, which is the lower prism that provided the highest stereoacuity on TNO stereotest. When the phoria size did not match the increments of the prism bars, the prism was rounded down for prism prescribing. For example, for a phoria of 7 PD, the prism was rounded to 6. This probably resulted in the average prism value being reduced.

The next flow chart demonstrates the SPC calculation procedure:

Flow Chart 1: SPC calculation procedure



Flow Chart 1: *The flow chart demonstrates the SPC calculation procedure. Subject exits with one of three possible outcomes: 1) 1000" stereo / no prism: 2) 15" stereo / no prism: 3) maximum stereo (480"-15") / prism value (2pd up to phoria size) combination.*

3.5.1.2. Dispensing aspect

Two pairs of spectacle corrections using the same frame (model and colour) were made. On one, a Fresnel prism was glued in according to Sheard's Criterion, and on the other, a Fresnel prism was glued in according to the SPC.

The participant was asked to wear the spectacle correction on an ongoing basis for one and a half months. The third appointment was held six weeks (± 3 days) later.

3.5.1.3. Fresnel Prism

The Fresnel prism was glued on the back surface of the lens in front of the non-dominant eye. To establish the dominant eye, a patient (with a full distance correction) was asked to form a triangular “window“ about 5 cm. on a side with his hands and through this window, while the hands were fully extended, to fixate on an optotype two lines bigger the maximum visual acuity eyes that see worse. By covering the left and right eyes in turn, the optometrist determined which eye, when the other was covered, kept the target in the centre of the triangle. This eye was determined to be the dominant one.

There are PD steps in the Fresnel prisms that are 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12,15, 20, 25, 30 and 40. In cases where there was no appropriate Fresnel prism amount, a stationary prism was given with Fresnel on it. For example, if a relieving prism of 22 PD was needed, a 1 PD stationary prism was ordered in right and left lenses, and 20 PD Fresnel was glued over a non-dominant eye.

3.5.1.4. Randomisation

The participant was provided with one of the pairs in a randomised, double-blind manner. The lenses were ordered from the manufacturer (Shamir), and after they were received at the author’s clinic, the lenses were checked for defects and non-compliance with the ordered parameters. Next, both orders were collected (with specific values of the prisms) and sent to the laboratory for insertion of the lenses into the frames. After receiving the orders, both glasses were checked for both pairs of glasses were checked for defects, manufacturing errors and compliance with the ordered parameters. Within the framework of this study, there were no cases where glasses failed inspection. After checking, both pairs, without notes about the value of the prism, were packed into a bag with the participant’s name only. From that moment on, the researcher did not know which glasses had what prism value. When a participant came to collect glasses, a pair of glasses was randomly selected and provided.

After the subject returned both pairs of glasses (at the end of the fourth appointment), filled in the modified CISS questionnaire, and proceeded with the tests, the glasses were checked, and the prism value was determined for each pair. Thus, the correspondence of specific glasses with the criterion of prismatic correction was revealed. After this, it became possible to correlate the method of prescribing the prism with the results of the tests and questionnaire.

The tests were carried out according to the protocol (Table 8).

Table 8: The Second Appointment Protocol - Stereopsis is Compromised	
GROUP 1 (SC) **Prism calculation -** measuring the minimal BIN (**relieving prism**) that gives the maximum stereo.	
Frisby minimal BIN for maximum stereo TWO-min Break	
Titmus (3 repetitions) minimal BIN for maximum stereo TWO-min Break	
Randot (3 repetitions) minimal BIN for maximum stereo TWO-min Break	
TNO (3 repetitions) minimal BIN for maximum stereo	
FR (something/blur/breaking/recovery) using TNO 480” TWO-min Break	
FR (something/blur/breaking/recovery) using Titmus 400” TWO-min Break	
PRISM 1 - Sheard’s criteria (2/3 Phoria – 1/3 PFR) PRISM 2 - The minimal relieving prism, which gives the higher global stereopsis (on TNO at 40 cm.)	

Table 8: *The second appointment protocol for Group 1.*

3.6. The Third Appointment

The third appointment was held six weeks (± 3 days) later and took up to forty-five minutes. The participant filled in the modified CISS questionnaire. During the third appointment, the tests were performed with full correction using a trial frame, including prism correction according to the prism amount the participant had been using for the last six weeks. The tests were carried out according to the protocol (Table 9).

Table 9: The Third Appointment Protocol	
Modified CISS questionnaire	
CT	
FD (Mallett Unit)	
Vergence Facility 12BO/3BI or 6 BO/3 BIN	
Titmus	
TNO	
FR (something/blur/break/recovery) TNO 480”	
FR (something/blur/break/recovery) Titimus 400”	

Table 9: *The third appointment protocol.*

The spectacle correction with the Fresnel prism was switched. The participant was asked to wear the spectacle correction on an ongoing basis for one and a half months. The fourth appointment was held 6 weeks later (± 3 days).

3.7. The Fourth Appointment

The fourth appointment, held six weeks (± 3 days) later, took up to forty-five minutes. The same test was performed on the third appointment (see 3.6). The participant filled in a modified CISS questionnaire. During the third appointment, the tests were performed with full correction using a trial frame, including prism correction according to the prism amount the participant had been using for the last six weeks. The tests were carried out according to the protocol (Table 10).

Table 10: The Fourth Appointment Protocol	
Modified CISS questionnaire	
CT	
FD (Mallett Unit)	
Vergence Facility 12BO/3BI or 6 BO/3 BIN	
Titmus	
TNO	
FR (something/blur/break/recovery) TNO 480”	
FR (something/blur/break/recovery) Titimus 400”	

Table 10: *The third appointment protocol.*

The experiment is described in Chapters 4 and 5.

3.8. The "FD Group"

The participants in the FD group (Chapter 5) underwent their first appointment with the same tests as described previously (section 3.4). The second appointment was held six weeks later (± 3 days). The protocol was exactly the same as described at the first to fourth appointments (2,4, 2,5, 2,6, 2,7), with the exception that Prism 2 was prescribed according to the FD method instead of the Sheard's Criterion.

The tests were carried out according to the protocol (Table 11).

Table 11: The "FD Group" second appointment	
PRISM 1 – FD method	
PRISM 2 - The minimal relieving prism, which gives the higher global stereopsis (on green book TNO)	

Table 11: *The second FD Group appointment protocol.*

The third appointment was held six weeks (± 3 days) later and took up to forty-five minutes. The participant filled in a modified CISS questionnaire. The tests were performed with prismatic spectacle correction provided at the previous appointment. During the third appointment, the tests were performed with full correction using a trial frame, including prism correction according to the prism amount the participant had been using for the last six weeks. The tests were carried out according to the protocol (Table 12).

Table 12: The "FD Group" third appointment	
Modified CISS questionnaire	
CT	
FD (Mallett Unit)	
Vergence Facility 12BO/3BI or 6 BO/3 BIN	
Titmus	
TNO	

Table 12: *The third FD Group appointment protocol.*

The fourth appointment was held six weeks (± 3 days) later and took up to forty-five minutes. The participant filled in a modified CISS questionnaire. The tests were performed with prismatic spectacle correction provided at the previous appointment. During the third appointment, the tests were performed with full correction using a trial frame, including prism correction according to the prism amount the participant had

been using for the last six weeks. The tests were carried out according to the protocol (Table 13).

Table 13: The "FD Group" fourth appointment	
Modified CISS questionnaire	
CT	
FD (Mallett Unit)	
Vergence Facility 12BO/3BI or 6 BO/3 BIN	
Titmus	
TNO	

Table 13: *The fourth FD Group appointment protocol.*

The glasses dispensing and randomisation were carried out in the same way as in Group 1 (see 2.4.1).

3.9. The "Normal Group"

The participants in the normal group (Chapter 2) underwent their first appointment with the same tests as described previously (see section 3.4). The second appointment was held six weeks (± 3 days) later. The tests were carried out according to the protocol (Table 14).

Table 14: The Second Appointment Protocol – The Normal Group	
Modified CISS questionnaire	
CT	
FD (Mallett Unit)	
Vergence Facility 12BO/3BI or 6 BO/3 BIN	
Frisby	
Titmus	
Randot	
TNO	
TNO Trombone (from 80 cm)	

Table 14: *The Normal Group appointment protocol.*

The FR was the same way as the protocol and in the same way, as described previously (Table 7).

3.10. Group 2 (SN) - Stereopsis is not compromised

A limited group of participants met all inclusion criteria (Table 3) except for the stereoacuity reduction (Chapter 6). Since not all inclusion criteria were met, this group was analysed separately. TNO, Titmus, Randot, and Frisby were used to measure the participants' stereoacuity. Those tests do not allow measuring the patient's full stereoacuity ability because the tests do not go beyond the specified value and have a fairly large step. It is possible that with the use of the compensating prism, stereopsis would become higher, as well as the results of the other clinical tests. Moreover, using a more sensitive stereotest may show reduced stereoacuity in such patients. The same tests are used, but the measurements are taken at a greater distance while the viewing angle becomes smaller and the stereopsis becomes higher. This measurement technique can allow for the measurement of the stereopsis threshold, which is the best stereoacuity that the patient is capable of.

An approach of doubling the test distance while measuring stereoacuity on Titmus and TNO was applied in this experiment. Doubling the test distance leads to decreased stereopsis. This was done to extend the range of the Titmus and TNO tests and get a finer threshold of stereopsis. This experiment hypothesised that if this approach demonstrates a compromised stereoacuity, the SPC can be applied (to the measurement gained at 80 cm.) since it would be evidence for exophoria decompensation in this group that failed Sheard's Criterion. Measuring stereo at 40 SOA did not provide evidence of reduced stereoacuity. The stereoacuity measured at 40 cm. gave at least 40 SOA on one of the stereotests applied in this research, not because the participants did not have a decompensated heterophoria but because they were not pushed hard enough on the stereotest to illustrate the fact that they had a reduced stereotest. To reveal a compromised stereoacuity by increasing the sensitivity of the stereotest makes it possible to apply the SPC. Stereoacuity measurements were performed with Frisby, Titmus, Randot, and TNO.

Group 2 (SC) included participants with decompensating heterophoria with no compromised stereoacuity. The participants underwent two appointments. The tests at the first appointment were the same as described earlier.

The second appointment for Group 2 (SC) appointment included:

- Stereoacuity measurement with Titmus at 40 cm;
- Stereoacuity measurement with Randot at 40 cm;
- Stereoacuity measurement with Frisby at 40 cm;
- Stereoacuity measurement with TNO at 40 cm;
- Stereoacuity measurement with Titmus at 80 cm;
- Stereoacuity measurement with TNO at 80 cm;

A two-minute break was taken between each test.

The tests were carried out according to the protocol (Table 15).

Table 15: The Second Appointment Protocol Stereopsis - The Normal Group	
GROUP 2 (SC) To **compromise** the stereo with BOUT	
Titmus 40 cm TWO-min Break	
Randot 40 cm TWO-min Break	
Frisby 40 cm TWO-min Break	
TNO 40 cm TWO-min Break	
Titmus 80 cm TWO-min Break	
TNO 80 cm TWO-min Break	
PRISM 1 - Sheard's criteria (2/3 Phoria – 1/3 PFR) PRISM 2 - The minimal relieving prism, which gives the higher global stereopsis (on TNO at **80 cm**.)	

Table 15: *The second appointment protocol for Group 2.*

Two sets of prisms were calculated. One is according to Sheard's Criterion, and the other is according to the SPC after the Prism Adaptation Test (PAT). The PAT procedure is discussed in section 3.11. The SPC for this group of participants was applied while the stereoacuity was measured at 80 cm.

3.11. Prism Adaptation Aspect

When a prism is placed in front of the eye, it evokes disparities between the retinal images from the two eyes; a fast vergence system rotates the eyes to avoid diplopia (Przekoracka-Krawczyk et al., 2019). The slow vergence mechanism changes the vergence state back to the original tonic phoria (Schor, 1979), reducing the fast fusional vergence response output and decreasing its effort (Thiagarajan, 2008). While an individual with normal binocular vision fixates on a target, the person will use relatively accurate and fast compensating eye movements to minimise the disparity between the eye's current vergence angle and the fixating target. The “slow” fusional vergence component serves to adapt to far or near visual scenes slowly. It can be assessed by the FD (Santos, Yaramothu & Alvarez, 2018).

Excessive vergence effort caused by prolonged viewing through a prism. Przekoracka-Krawczyk et al. (2019) demonstrated that subjects with heterophoria that are not compensated have a vergence prism adaptation deficiency. The author hypothesise that this deficit is the reason for limited FR and asthenopia symptoms during prolonged fixation. In their study, subjects with high but asymptomatic heterophoria demonstrated reduced adaptation rates. However, after four minutes of binocular viewing, the subjects could adapt to a similar level as subjects with normal binocular vision.

If a test is performed with a prism, prism adaptation may occur. This means that the supposedly reduced (by the relieving prism) heterophoria has fully or partially returned to its original value (North & Henson 1982). This adaptation occurs to a greater extent when the heterophoria is high (Ogle et al. 1967). Crone and Hardjowijoto (1979) also reported the same phenomenon. To avoid prism adaptation and to reduce the load on the visual system, FRs were measured last.

3.11.1. Fast vergence adaptation

Subjects with binocular dysfunction tend to adapt to the prism (Gray, 2008). There is no consensus in the literature regarding the time period during which the slow vergence mechanism adapts to the prism. Henson and North (1980) demonstrated on eight normal subjects that prism adaptation occurs within two to three minutes, and

Wong, Rosenfield, and Wong (2001) ran a study with 5 min adaptation. Schor et al. (2019) reported that the effect of exposure to BI prism with an amount according to the associated phoria (FD) for 60 seconds was similar to the effect of exposure for 2-5 sec exposure, which means that within one minute, no adaptation occurs.

To avoid prism adaptation and transfer of the binocular vision system from the fast vergence mechanism to the slow, all tests that needed a prism were carried out within 3-4 minutes.

3.11.2. Slow vergence adaptation

Sreenivasan, Irving and Bobier (2012) evaluated the vergence and accommodation change during prolonged near visual tasks that lasted for 2, 4, 6, 8, 10, 15 and 20 min. The authors found that among exophores, the near task increased the deviation angle, and the higher the baseline exophoria, the greater the vergence adaptation. The major phoria change in this group was within the first 10 minutes of the near visual task. Wu et al. (2016) ran a study to evaluate the effect of 10 minutes of adaptation. Takada et al. (2021) reported that – the 30-minute PAT test was more effective than monocular occlusion for 30 and 60 minutes in evaluating the near deviation change. On the other hand, there was no significant difference in the near deviation angle between PAT for 30 and 60 minutes.

After the prism was calculated and put in the trial frame in the experiments in this research, a prism adaptation test (PAT) was performed. PAT was performed for 30 minutes to refine the prism after prism adaptation, during which the participants were asked to perform a near task (reading). After the PAT, the prescribed prism amount was reevaluated to ensure that the prism calculated previously did not change after the prism adaptation:

- In the case of Sheard's Criterion, CT and FR were measured over the prism with which the participant took the PAT test. If the calculated prism after the PAT was different from the previous one, the calculation after PAT was recorded as a prism calculated according to Sheard's criteria.
- In the case of the SPC, the prism was re-measured using the TNO as described above over the previous prism with which PAT was performed PAT test. If the prism was different from the previous (before PAT), the

prism amount gained after PAT was recorded as a prism calculated according to the SPC.

3.12. The appointment Timing

Binocular vision test results performed at the beginning of the working day or in the afternoon after several hours of close work will differ (Yekta et al., 1987). Yekta et al. (1987) compared the heterophoria angle and the FD performance among 84 young adults. The authors found a statistically significant increase in the heterophoria angle as well as the FD throughout the day but did not mention the day of the week. To avoid bias, all the appointments took place at the same time of the day; if the first one was on the weekend or weekday, the other appointments were accordingly. All the tests at all the appointments were performed with an assistant who recorded the results.

4. The Relieving Prism Prescribing, According to Sheard's versus the SPC

4.1. Introduction

One currently used method for prism prescribing in some clinics (including the author's) is based on Sheard's Criterion, which was developed in the 1930's reference. (See Chapter 5 for Fixation Disparity, the other commonly used approach). It is a motor approach, considering the patient's exophoria and the positive fusional reserves opposing it.

The formula for Sheard's Criterion is:

$$P = (2/3\ D - 1/3\ R)$$

where P is the prism, D is the amount of the deviation (the CT result), and R is the amount of the compensating FR (the blur point).

Scheiman et al. (2020) conducted a literature review investigating non-surgical treatment options for decompensating exophoria. The authors found that many treatments were unconvincing and that prismatic reading glasses were no more effective than placebo reading glasses. A small study by Summers et al. (2023) agrees with the previous. The lack of a statistically significant difference may be because the prism was prescribed according to the currently used criteria (Sheard's and FD), whose accuracy is questionable (Scheiman et al., 2005).

However, stereopsis, not considered in Sheard's Criterion, plays an important role in the behaviour of the binocular system. Stereoacuity refers to the three-dimensional understanding of the visual scene and points to the binocular system's efficiency and the interaction of its motor and sensory components. Stereopsis indicates the efficiency of the entire binocular system as a whole. The higher the stereoacuity, the more properly the binocular system works.

The vast majority of patients with decompensating heterophoria have reduced stereopsis (Schroth et al., 2015). Furthermore, global stereopsis has decreased more than local stereopsis, suggesting global stereopsis is more sensitive to decompensation

(Momeni-Moghadam et al., 2011). The pilot study demonstrated that an induced exophoria among subjects with normal binocular vision brings the TNO to be more compromised than Titmus and Randot. Moreover, among symptomatic subjects with decompensating Exophoria, TNO was more compromised than Titmus and Randot (Rinsky, 2017). Different neural processing refers to global and local stereopsis, and global is more vulnerable to binocular vision dysfunction (Momeni-Moghadam et al. 2011; Vancleef et al. 2017). A difference between local and global stereopsis was discussed in Chapter 1.

The newly developed prism prescribing criterion, the Stereo-Prism Criterion (SPC) is based on the TNO stereotest, a commonly used global stereo test in optometry practice (Zhao & Wu, 2019). SPC refers to the ***minimum prism amount that provides the highest global stereoacuity*** using TNO. This experiment aims to answer the question of which relieving prism prescribing method will provide the patients with better stereopsis and greater symptom relief: the newly developed SPC or the currently used Sheard's Criterion. The hypothesis is that the SPC provides better symptom relief than Sheard's Criterion. If global stereopsis is more readily compromised in decompensating phoria, then maximising the stereo may generate a higher relieving prism value, resulting in a greater reduction of symptoms. It may generate a higher relieving prism value, therefore giving better compensation, which should give a better reduction of symptoms. It proved that the extra value of the prism provided a better state of compensation. Phoria was less compensated with a higher amount of prism derived from using the TNO. Therefore, the expectation was that the symptom relief would be greater with the TNO value as opposed to the Sheard's value. If Sheard's Criterion was as good as SPC, then Sheard's would also maximise the stereo. But it did not and left the phoria to be still decompensating. Therefore, it's inadequate.

4.2. Methodology

4.2.1. Participant's selection

Two sets of relieving prismatic pairs of glasses, which corrected for the participant's refractive error, were prescribed in a randomised, double-blind, cross-over manner (See Chapter 3). The participants were asked to use the glasses for one and a half months.

The prism was calculated according to Sheard's Criterion in one case and the SPC in the second.

4.2.2. Two Sets of Prismatic Spectacles

The participants were divided into two groups: one using prism according to Sheard's Criterion and the other according to SPC.

To evaluate the relieving prism efficiency, the participants filled in a questionnaire at the baseline (with no relieving prism) and after each prismatic correction period. In this research, the CISS questionnaire was used with a minor modification. To the best of the author's knowledge, there is no better alternative to SICC. Although the limitations of CISS are acknowledged. Since the modifications were minor, they can be considered as a valid instrument. The prism prescribing method that provided better symptom relief satisfaction was considered beneficial. The questionnaire score of zero indicated that the participant had no symptoms, and the maximal score of sixty indicated severe symptoms. Moreover, global and local stereo acuity was measured at the baseline and after each period of prismatic correction, as well as the other tests described in Chapter 3, to evaluate the performance of the binocular system.

The randomisation, appointment timing, PAT and dispensing methods are described in Chapter 3.

4.3. Results

4.3.1. The Participants

Seventy-five participants were recruited for this experiment. Six participants lost to follow-up, and sixty-nine were analysed. The mean age of the participants was 29.9, ±9.76 years old. Of the 69 subjects, 32 (46.3 %) were female and 37 (53.7 %) males. All 69 subjects underwent all the examinations. All participants had a decompensating exo deviation at near and met the (Table 3) criteria.

4.3.2. Stereoacuity Results

Titmus and TNO are the most commonly used stereotests in the optometry practice (Zhao & Wu, 2019). The author was aware of unconscious bias in hypothesising that TNO will be more compromised by heterophoria decompensation and, therefore, will generate a higher amount of relieving prism, which will lead to greater symptom relief. The stereoacuity gained with these two tests was assessed with different relieving prism amounts.

The Initial Stereoacuity mean measured with Titmus and TNO (218.84, ±180.47 SOA and 399.13, ±191.54 SOA, respectively) was more compromised than the stereoacuity mean gained with a prism prescribed according to Sheard's Criterion (Titmus 55.80, ±17.25 SOA; TNO 111.67, ±87.12 SOA). The magnitude of the change for Titmus was 163.04 SOA, and for TNO was 287.46 SOA. The mean stereoacuity gained with a prism prescribed using the SPC was better (Titmus 42.32, ±8.25 SOA; TNO 43.7, ±25.45 SOA) compared to Sherard's Criterion. The magnitude of the change for Titmus was 176.52 SOA, and for TNO was 355.43 SOA. Table 16 represents the stereoacuity mean ± S.D. measured with TNO and Titmus stereotests with no prism correction, with relieving prism prescribed according to Sheard's Criterion and with prism according to the SPC. That suggests that TNO was more compromised in phoria decompensation.

The SPC brought stereopsis to be virtually normal. The standard deviation was reduced with the SPC on both stereotests compared to the baseline measurement, meaning the data is much less noisy. Even though the standard deviation was reduced with the SPC on TNO compared to the baseline measurement, it was still noisy. That suggests that there is still room for improvement (the standard deviation of 25.45 SOA) in further work. Being able to measure the stereoacuity with better accuracy in smaller steps to a higher degree and with smaller prism steps (instead of a prism bar) may enable a more accurate calculation of a prism value. With the SPC prism, some participants still had a non-perfect (40 SOA) stereoacuity. With an even higher relieving prism, they might get a higher stereoacuity. Improving the accuracy of calculating the SPC can result in a demonstration of a further stereoacuity improvement with more prism in those participants who still had a potential reduction, which will then reduce the noise.

Table 16: Stereoacuity mean ± S.D. measured with TNO and Titmus stereotests with no prism correction, with relieving prism prescribed according to Sheard's Criterion and with prism according to the SPC

Stereoacuity measurement conditions	Titmus			TNO		
	Mean	SD	The magnitude of the mean change	Mean	SD	The magnitude of the mean change
Stereoacuity with no prism correction	218.84*	180.47		399.13*	191.54	
Stereoacuity with relieving prism prescribed according to Sheard's Criterion	55.80*	17.52	163.04	111.67*	87.12	287.46
Stereoacuity gained with prism prescribed according to the SPC	42.32*	8.25	176.52	43.70*	25.45	355.43

Table 16: *With no relieving prism, TNO was significantly more compromised than Titmus ($p<0.05$). With Sheard's Criterion, there was a significant improvement in both stereotests ($p<0.05$), but TNO was significantly more compromised than Titmus ($p<0.05$). With the SPC, there was a further improvement (significant with TNO; $p<0.05$) in both, and they were both performing on an equal level and at virtually normal levels ($p>0.05$). * means that there was a statistically significant difference.*

Figure 2 demonstrates a trend of increasing stereoacuity with increasing relieving prism measured with Titmus and TNO. The stereo was measured at a different appointment, with no relieving prism, with a relieving prism prescribed according to Sheard's Criterion and a prism prescribed according to the SPC. The SPC contributed to a higher stereoacuity for both Titmus and TNO. Shapiro-Wilk demonstrated that the data were not normally distributed (Table 17).

Table 17: Shapiro-Wilk results for stereoacuity tests measured in different conditions				
Stereotest and measurement condition	Statistic	df	p	Outcome
Titmus with no prism	0.719	69	<0.001	The data are not normally distributed
TNO with no prism	0.762	69	<0.001	The data are not normally distributed
Titmus with Sheard's Criterion Prism	0.799	69	<0.001	The data are not normally distributed
TNO with Sheard's Criterion Prism	0.681	69	<0.001	The data are not normally distributed
Titmus with SPC	0.533	69	<0.001	The data are not normally distributed
TNO with SPC	0.783	69	<0.001	The data are not normally distributed

Table 17: *Demonstrates that stereoacuity measured in different conditions provided a non normalized data using Shapiro-Wilk test.*

Since the data were not normally distributed nonparametric tests were performed. Friedman test showed a statistically significant difference (N=69, Chi-square=278.178, df=5, p<0.001) in the stereoacuity mean, and the Wilcoxon Signed Rank test showed a significant difference between each stereoacuity mean except for the mean stereoacuity measured using Titmus with SPC and stereoacuity measured using TNO with SPC (Table 18).

Table 18: Stereoacuity mean measured with TNO and Titmus stereotests with no prism correction, with relieving prism prescribed according to Sheard's Criterion and with prism according to the SPC comparison using Wilcoxon Signed Rank test

Stereotest and measurement condition	Stereotest and measurement condition	z	p	Outcome
Baseline Titmus	Baseline TNO	-6.575	<0.001	Statistically significant
Baseline Titmus	Titmus with Sheard's	-7.224	<0.001	Statistically significant
Baseline Titmus	TNO with Sheard's	-4.985	<0.001	Statistically significant
Baseline Titmus	Titmus with SPC	-7.236	<0.001	Statistically significant
Baseline Titmus	TNO with SPC	-7.052	<0.001	Statistically significant
Baseline TNO	Titmus with Sheard's	-7.237	<0.001	Statistically significant
Baseline TNO	TNO with Sheard's	-7.036	<0.001	Statistically significant
Baseline TNO	Titmus with SPC	-7.343	<0.001	Statistically significant
Baseline TNO	TNO with SPC	-7.194	<0.001	Statistically significant
Titmus with Sheard's	TNO with Sheard's	-6.427	<0.001	Statistically significant
Titmus with Sheard's	Titmus with SPC	-5.477	<0.001	Statistically significant
Titmus with Sheard's	TNO with SPC	-4.146	<0.001	Statistically significant
TNO with Sheard's	Titmus with SPC	-6.867	<0.001	Statistically significant
TNO with Sheard's	TNO with SPC	-6.379	<0.001	Statistically significant

Titmus with SPC	TNO with SPC	-0.371	7.11	Not statistically significant

Table 18: *The mean stereoacuity measured using Titmus and TNO with relieving prism prescribed according to SPC was not statistically significantly different (p=7.11).*

Even with the SPC, the TNO was still noisy, with a relatively high SD. However, TNO was more affected by the relieving prism amount than Titmus, with an improvement with Sheard's Criterion prism and an even better improvement with SPC, which did not happen with Titmus. Therefore, TNO was shown to be better equipment than Titmus for prism prescribing, which is in agreement with the previous experiment, the Pilot study (Rinsky, 2017).

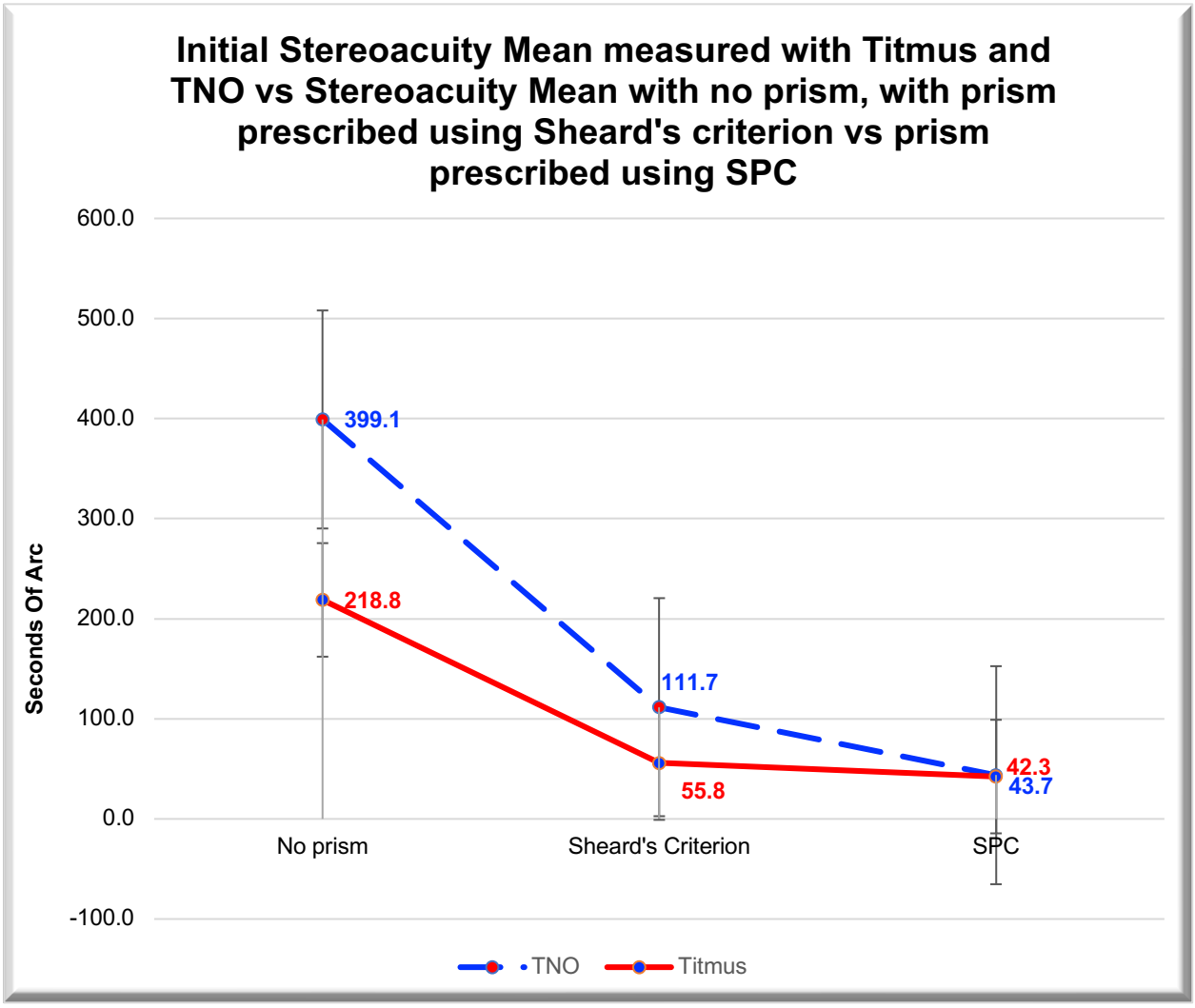


Figure 2: *The graph shows the improvement of stereopsis with relieving prism. Between Sheard's Criterion and stereopsis, Titmus was less affected by the difference in the amount of prism. However, TNO was sensitive to those changes being more*

compromised with no prism, less compromised with Sheard's prism, and virtually normal with SPC. The error bars represent the Standard Deviation of the mean.

With an increase in the prismatic component, stereoscopic vision improves. This effect is more pronounced with TNO, again indicating greater TNO compromise in comparison to Titmus (Figure 3). Stereoacuity was measured at the baseline and between either stereoacuities measured with relieving prisms, prescribed according to Sheard's Criterion and the SPC. There was a statistically significant difference between stereoacuity means. TNO showed a difference between measurements with no prism and with prism prescribed with both criteria. However, Titmus showed no significant difference in stereoacuity using the current and SPC. On the other hand, TNO showed a significant difference between measurements without prisms and with each of the prisms and between measurements with both prisms. The lack of difference in stereoacuity with different prisms with Titmus and the presence of a difference in stereoacuity with TNO indicates that TNO is more compromised in heterophoria decompensation.

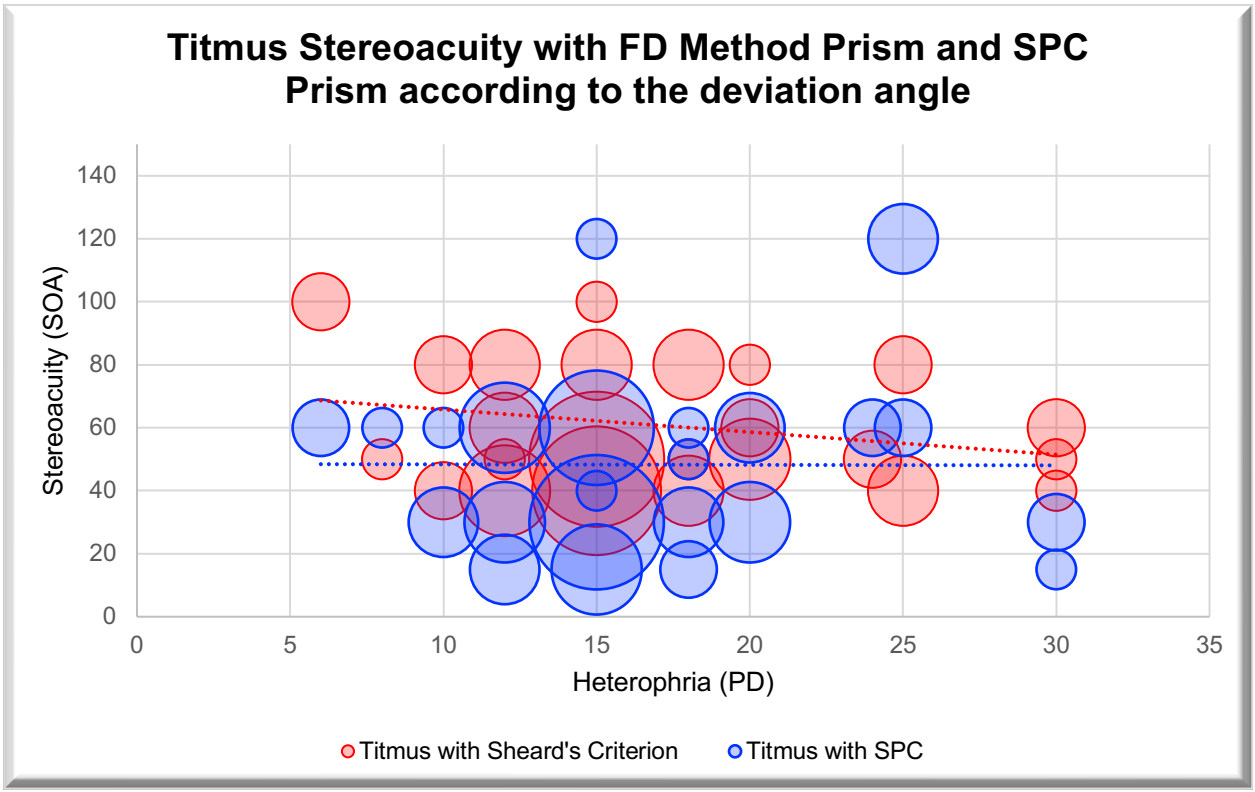


Figure 3: *Scatterplot showing that SPC provided a higher relieving prism contributing to greater stereoacuity than Sheard's Criterion using Titmus stereotest.*

Figure 4 shows that in 53.7% of subjects (37 subjects), SPC contributed to a higher stereoacuity than what was found with Sheard's Criterion. In 43.5% of subjects (30 subjects), there was the same stereoacuity with both prism amounts, and in 2.8% (2 subjects), Sheard's provided a greater stereoacuity than SPC. This means that SPC providing a higher relieving prism contributes to greater stereoacuity than Sheard's Criterion.

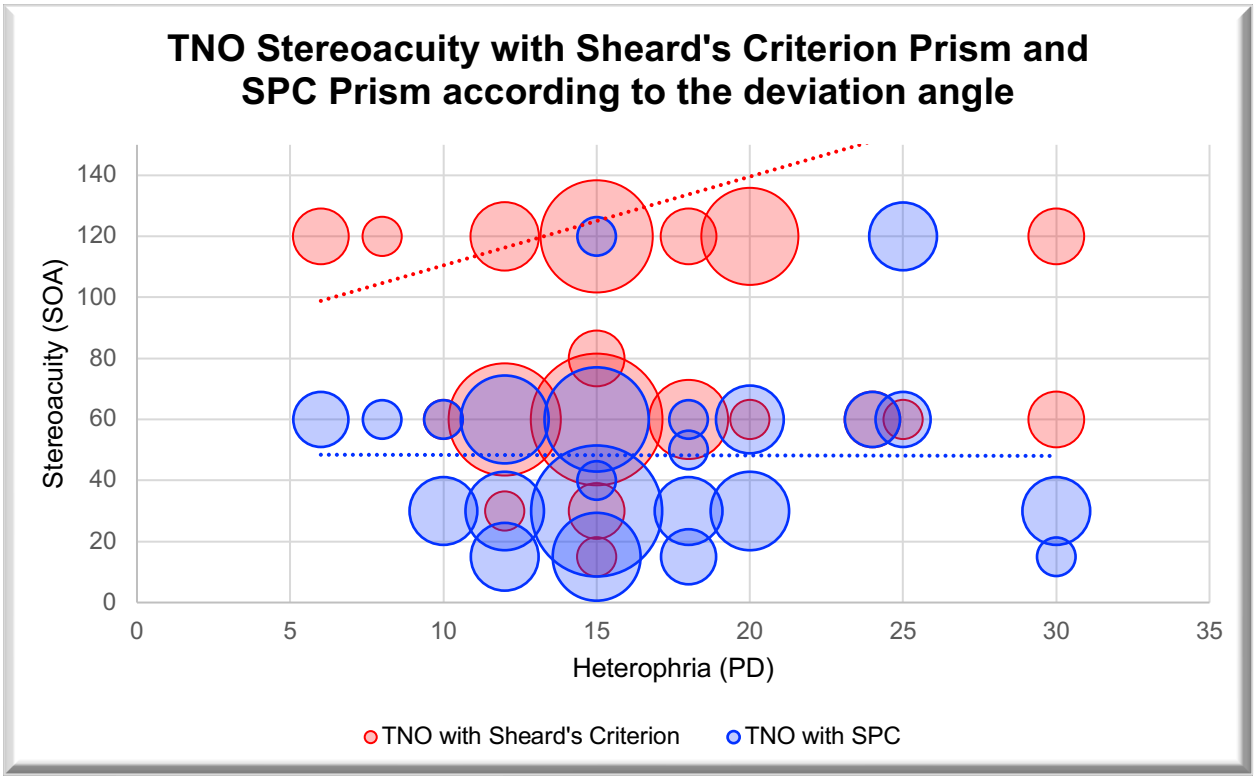


Figure 4: *Scatterplot showing that in most cases, the SPC contributed to a greater stereoacuity than Sheard's Criterion using TNO stereotest.*

Figure 4 shows that in 88.5% of subjects (61 subjects), SPC contributed to a higher stereoacuity than what was found with Sheard's Criterion. In 8.7% of subjects (6 subjects), there was the same stereoacuity with both prism amounts and in 2.8% (2 subjects), Sheard's provided a greater stereoacuity than SPC. This means that SPC providing a higher relieving prism contributes to greater stereoacuity than Sheard's Criterion.

Three participants demonstrated stereoacuity on one of the stereotests but no stereoacuity on all the tests at the baseline. Plotting a graph or running a statistic test without full data is impossible. Because of that, an "artificial" stereoacuity value of 1000

SOA was recorded as the stereotest result if the participant had no stereopsis on one of the stereotests. One participant failed to pass Randot and TNO, one failed TNO only, and one failed Randot, TNO and Frisby. The tests are not allowed to measure low stereoacuity, and because of that, it was impossible to measure all sets of data. This is also a reason for a high standard deviation on stereoacuity. The statistics and the plots without those three participants are presented in Appendix 4. The statistics show that those three participants did not affect the data or conclusion. Because of that, they are included in the main thesis.

Since TNO was demonstrated to be more affected in heterophoria decompensation than Titmus, it was chosen to be used at the SPC relieving prism criterion.

4.3.3. Prism Results

The mean relieving prism calculated according to Sheard's Criterion was (7.3, ±3.89 PD) lower than provided by SPC (13.03, ± 5.03 PD) (Figure 5). Shapiro-Wilk demonstrated that the data were not normally distributed (Sheard's Prism $p<0.001$; SPC Prism $p=0.003$). The Wilcoxon Signed Rank test showed a significant difference between the prism mean calculated according to Sheard's Criterion and the SPC ($z=-7.072$, $p<0.001$).

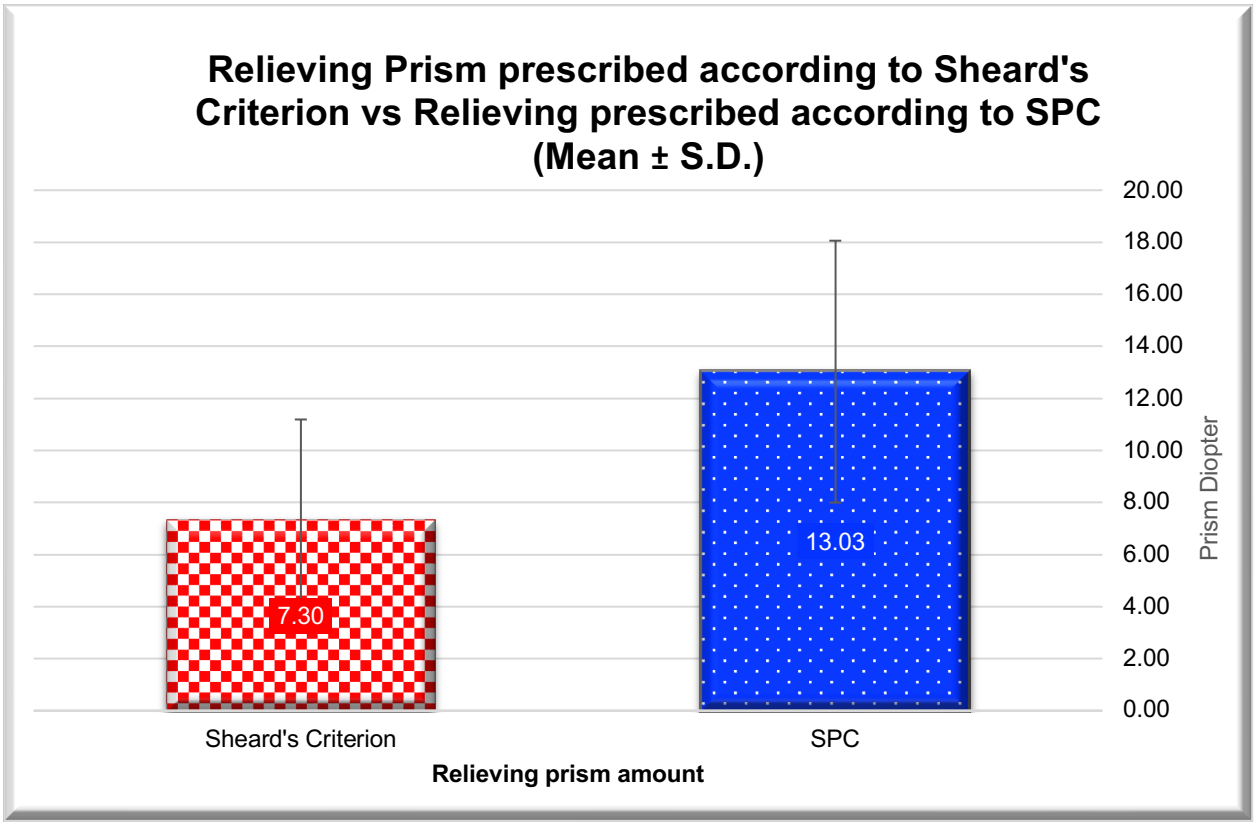


Figure 5: *The graph shows that the relieving provided by the SPC (13.03, ±5.03) was significantly higher than that provided by Sheard's Criterion (7.30, ±.89) with $p<0.05$. The error bars represent the Standard Deviation of the mean.*

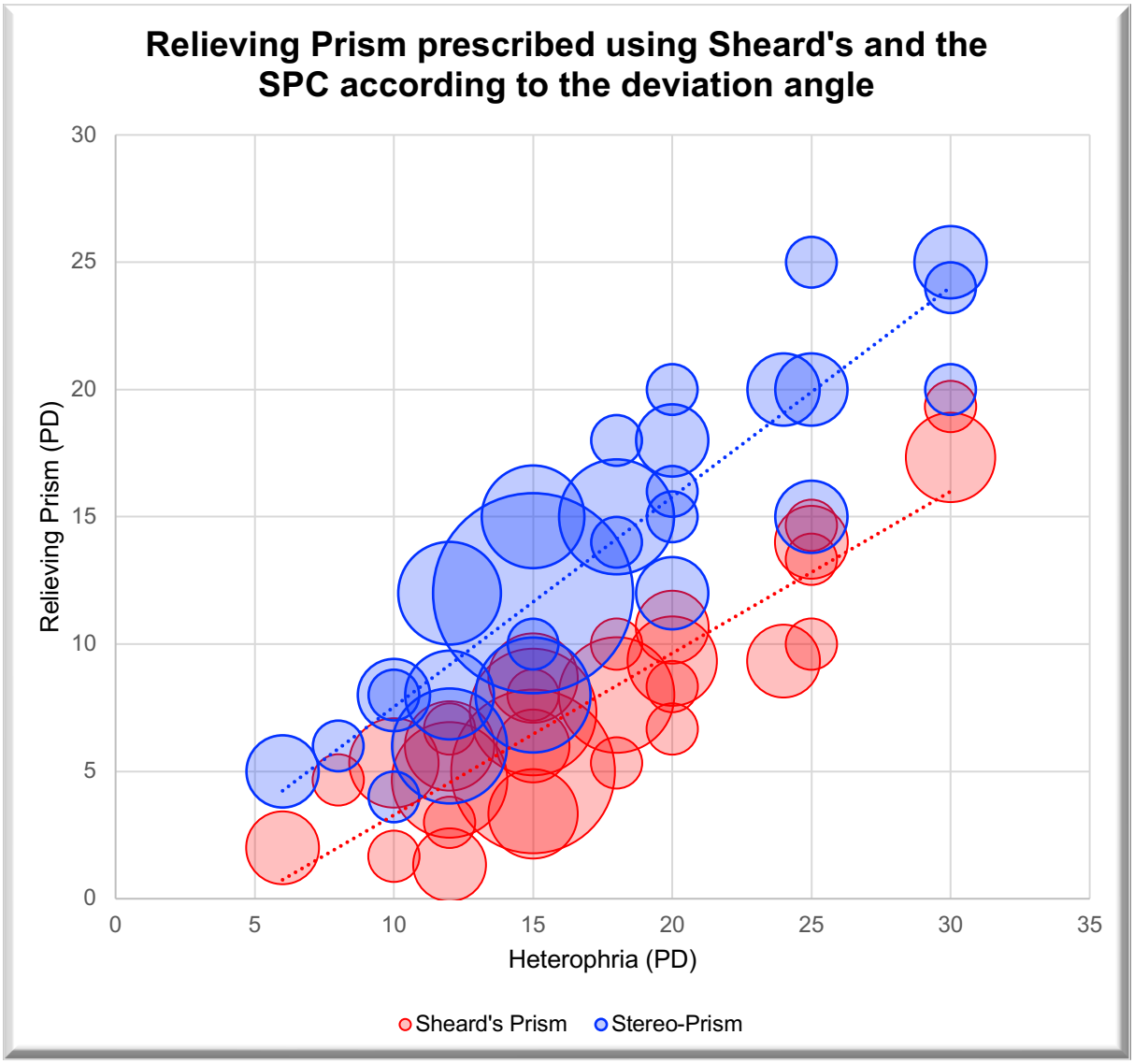


Figure 6: *Scatterplot showing that the relieving prism distribution prescribed according to the SPC was higher than that provided by Sheard's Criterion in all the cases.*

Figures 6, 7 show that the relieving prism amount prescribed with SPC was higher than that provided by Sheard's Criterion in every case.

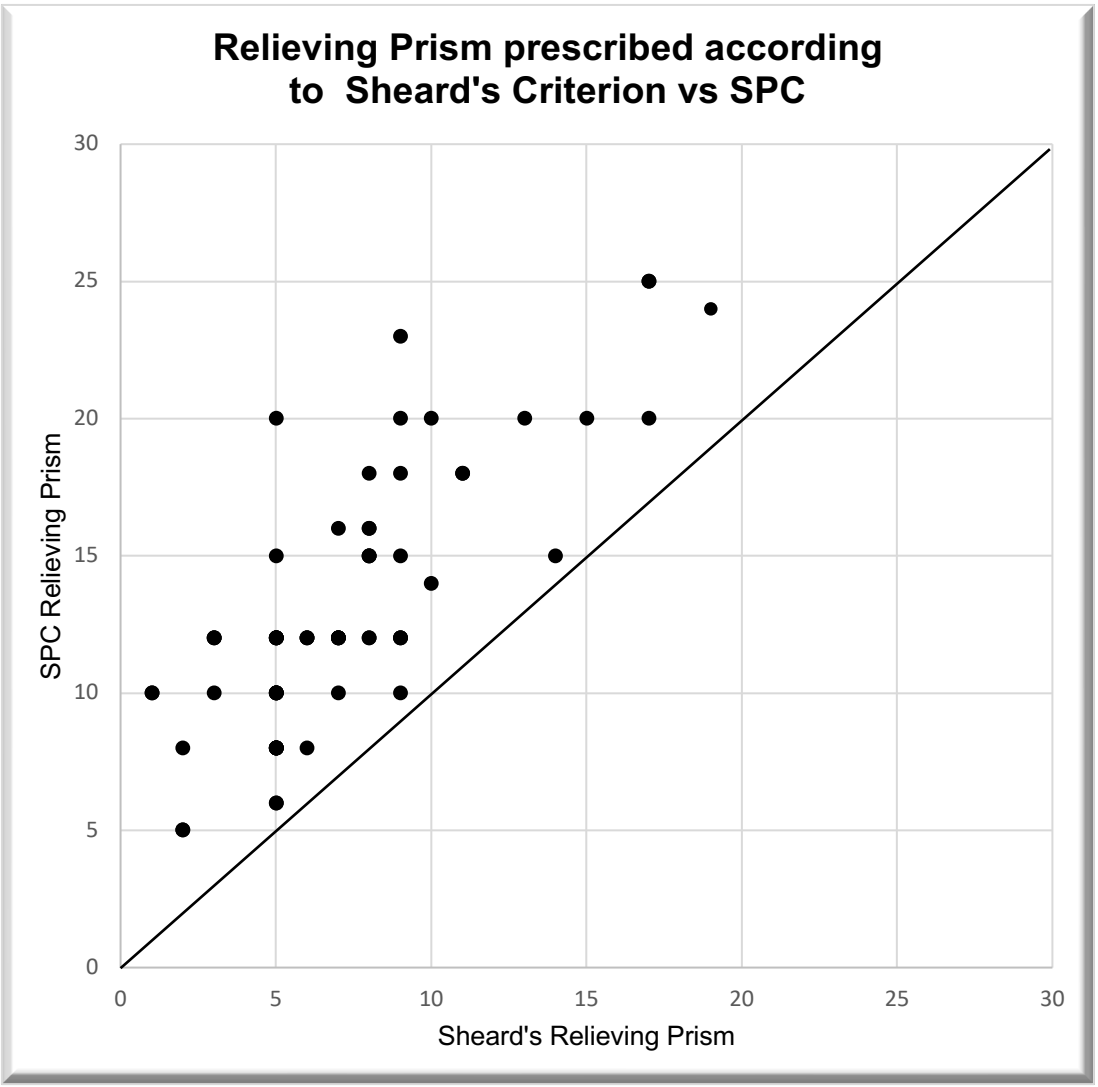


Figure 7**:** *Scatterplot showing that the relieving prism distribution prescribed according to the SPC was higher than that provided by Sheard's Criterion in all the cases.*

4.3.4. Questionnaire Results

At the initial appointment, the baseline modified CISS mean score was 42.00, ± 6.99, which was significantly higher than the score recorded after participants began wearing prismatic glasses prescribed based on Sheard's Criterion (29.52, ± 6.45). The mean CISS score improved even further with SPC, reaching 21.84, ± 6.94 (Figure 8). These findings indicate that SPC provided greater symptom relief compared to Sheard's Criterion Prism.

As can be seen from Figure 8, the SPC contributes to greater satisfaction and a lower symptom level. Shapiro-Wilk test showed that the questionnaires provided normally distributed data (Initial questionnaire Statistic =0.981, df=69, p=0.365; Sheard's questionnaire Statistic =0.967, df=69, p=0.066; SPC questionnaire Statistic =0.976, df=69, p=0.194). A comparison between the questionnaire's means was performed using the Repeated Measures ANOVA test. ANOVA showed a statistically significant difference with a very low p-value (p<0.001). The value of the test statistics is F=170.414 with a degree of freedom 2. A Tukey post-hoc test was performed to determine the significant difference between each test. The Tukey test showed a significant difference (p<0.001) between each measured questionnaire means (Table 19).

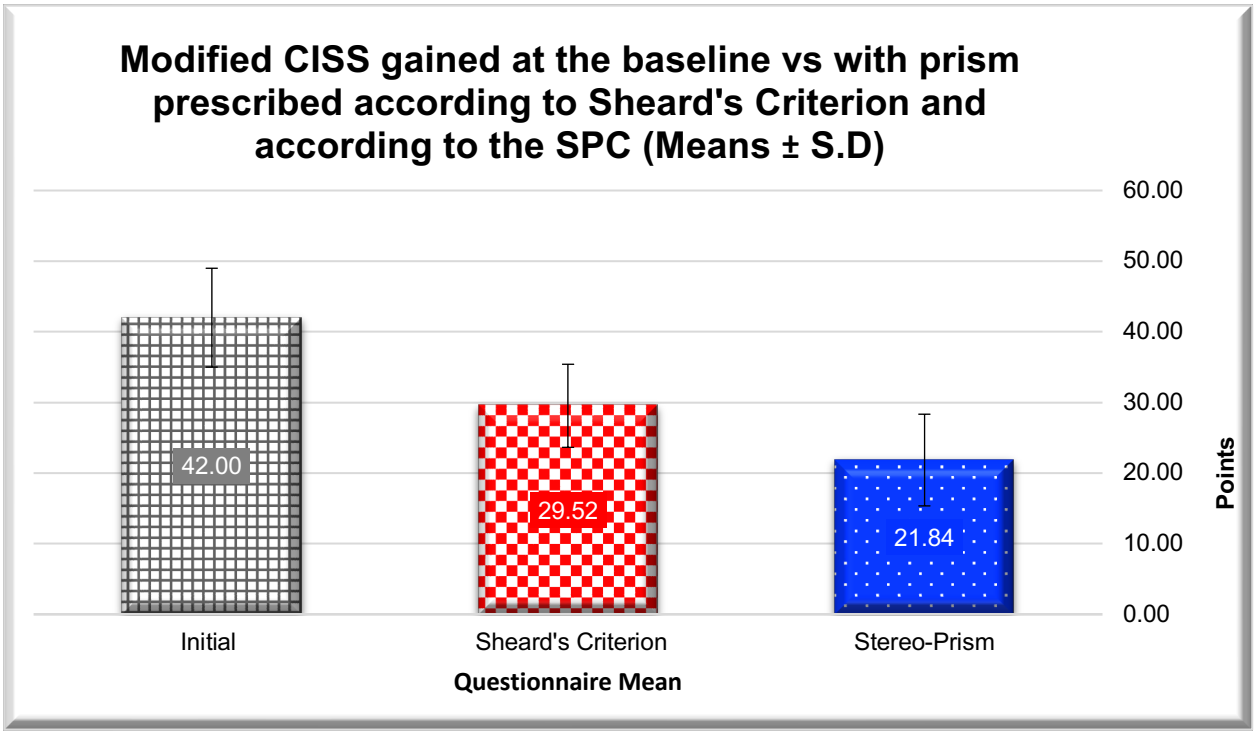


Figure 8: *The graph shows that the symptom relief level gained with the prism prescribed according to the SPC (21.84 ±6.49) was greater than with Sheard's* Criterion *(29.52 ±5.88), and both criteria provided a lower symptom level than that was at the baseline (42.00 ±6.99). The differences were significant (p<0.05). The error bars represent the Standard Deviation of the mean.*

Table 19: The Tukey post-hoc results for modified CISS measured at the baseline, with relieving prism prescribed according to Sheard's Criterion and SPC.					
Modified CISS measurement condition	Modified CISS measurement condition	Mean difference	Std. Error	P value	Outcome
Baseline	Sheard's	12.478	1.102	<0.001	Statistically significant
Baseline	SPC	20.159	1.102	<0.001	Statistically significant
Sheard's	SPC	-12.478	1.102	<0.001	Statistically significant

4.4. Discussion

The newly developed prism prescribing method, SPC, based on the TNO stereotests, showed greater compromise to heterophoria decompensation compared to Titmus. These two tests are most commonly used in the optometry practice (Zhao & Wu, 2019). SPC provided a higher relieving prism amount in every single case compared to Sheard's criterion. A higher prism value contributed to greater stereopsis with Titmus and TNO in the majority of the cases and better symptom relief satisfaction for the participants. However, symptom relief was significantly greater with SPC compared to Sheard's Criterion. This was confirmed with the modified CISS questionnaire, which was taken at the baseline and after both prismatic correction periods, one with Sheard's Criterion prism and the second with SPC. This indicates that the SPC was beneficial over Sheard's Criterion in relieving symptoms.

Significantly greater symptom relief was obtained with the modified CISS questionnaire among participants who were using a prismatic correction prescribed according to the SPC compared to what was gained with Sheard's Criterion prism and against the initial questionnaire mean. A higher questionnaire mean (a more severe symptom level) at the first appointment represents the initial satisfaction level when no prism was prescribed. There was symptom relief with a prism prescribed according to

Sheard's Criterion and even greater relief with a prism prescribed according to the SPC. The satisfaction level with the prism prescribed using Sheard's Criterion was greater by about 30% and greater by 48% using the SPC prism than what was at the baseline. Even though the obtained data were statistically significant, a placebo group was absent, which was a potential weakness of the research.

A relieving prism calculated according to Sheard's Criterion contributed to symptom reduction to a lower extent in comparison to SPC. Scheiman et al. (2005) conducted a prospective randomised, placebo-controlled, double-blind study with seventy-two symptomatic participants with convergence insufficiency. The participants were divided into two groups. The first group was provided with glasses that corrected for the patient's refractive error, if necessary and a base-in prism. The prism was calculated according to Sheard's Criterion. The second group was provided with placebo reading glasses with no prism. The participants were asked to wear these glasses for near tasks. Sheard's Criterion showed that the base-in prism reading glasses provided no more significant symptom relief than the placebo glasses. It agrees with the current experiment demonstrating insufficient symptom relief with the currently used prism prescribing criterion. On the other hand, Nabovati, Kamali, Mirzajani, Jafarzadehpur and Khabazkhoob (2020) demonstrated symptom relief with a prism prescribed according to Sheard's Criterion. Still, it had no significant effect on the binocular vision test performance. Nevertheless, the newly developed criterion provided a significantly greater relief, contributing to a higher relieving prism.

This experiment showed a statistically significant difference between the modified CISS questionnaire mean measured with no prism and a prism prescribed according to each criterion. The prism prescribed according to the SPC achieved greater symptom relief than Sheard's Criterion. The SPC was developed according to the Global stereoacuity, which is more readily compromised in phoria decompensation. This was demonstrated in this experiment. The weakness of the experiment was that a placebo group was not included. The global stereoacuity was more compromised than the local, which is in agreement with Momeni-Moghadam et al. (2011) and the pilot study (Rinsky, 2017).

4.5. Conclusion

Binocular vision anomalies contribute to stereoacuity reduction. The experiment results confirm that the TNO test was more compromised to the phoria decompensation status than the local tests. Therefore, global stereoacuity measurement should be included as a required test in the prism prescribing method. Stereoacuity is a substantial tool for assessing the highest form of binocular coordination (Ancona et al., 2014; Von Noorden et al., 1990; Ohlsson et al., 2001). The fact that TNO was shown to be more compromised than Titmus confirms that SPC should be based on TNO.

The SPC consistently gave a higher prism value and contributed to a higher stereoacuity in the vast majority of the cases on TNO compared with Sheard's Criterion, which confirms the TNO and SPC are beneficial over Sheard's Criterion.

Greater satisfaction was achieved with prismatic glasses prescribed according to the SPC, which provided a higher relieving prism value compared to Sheard's Criterion. Based on the foregoing, it can be concluded that the SPC is more beneficial than the current one in relieving symptoms.

The results confirm that the new approach improved satisfaction and was shown to be a beneficial prism prescribing method over Sheard's Criterion. Nevertheless, Gray (2008) claimed there was a lack of consensus and double-blind, placebo-controlled clinical studies regarding the appropriate prism amount prescribed to patients with heterophoria. The established Sheard's Criterion is not the only approach for prism prescribing for decompensating heterophoria (O'Leary & Evans 2003). The motor fusional ability may not reflect the efficacy of the criteria. The sensory component of binocular vision also affects stereoacuity.

Another prism prescribing technique based on sensory fusion is the FD method. This method was developed in the late 70s of the twentieth century (Sheedy & Saladin,1978a). According to Rae (2015), FD is the most common technique method for assessing phoria compensation in UK optometric practice. The limitations of this experiment are discussed in the 9.1 section.

5. The Relieving Prism Prescribing According to FD versus the SPC

5.1. Introduction

FD method using the Mallett Unit is more recent than Sheard's Criterion. FD was more recent than Sheard's, proposed in 1964 (Mallett,1964), and gained a lot of credibility, suggesting that it is probably a better prism prescribing method than Sheard's. The Mallett unit is the primary method most UK optometrists employ for detecting decompensated heterophoria and prescribing prisms (O'Leary & Evans, 20203). It has become an established practice to replace FR and Sheard's Criterion when prescribing prisms. The fact that FD became a more popular technique suggests that it is beneficial and presumingly more effective than Sheard's.

Since there is no evidence in the literature that FD is more beneficial than the SPC method, this study. investigated it In order to do so, a double-blind study was conducted, but instead of Sheard's Criterion, FD was compared to the SPC. This experiment compares the SPC Prism prescribing criterion with the commonly used FD method and determines which is more effective for symptomatic relief (Rae, 2015). Sheard's Criterion was less beneficial in symptom relief than the SPC (Chapter 4); however, FD was not assessed.

This experiment aimed to answer the question of whether there will be a difference in the relieving prism amount between three methods: Sheard's Criterion, the SPC and FD using the Mallett Unit and if so, which prism will contribute to greater symptom relief. The hypothesis was that the FD prism was higher than that calculated with Sheard's Criterion but lower than that calculated according to the SPC. A higher prism contributes to more significant symptom relief. The hypothesis was that FD would not provide a sufficient prism to address symptoms. Therefore, the participants will prefer a prism prescribed according to the SPC that provides a higher prism over the prism prescribed by FD.

5.2. Methodology

The FD method was applied to calculate the relieving prism using the Mallett Unit, the most commonly used device to measure FD (Karania & Evans, 2006). The prism was also calculated using Sheard's Criterion and the SPC among participants recruited for "The Relieving Prism Prescribing, According to Sheard's versus the SPC" experiment (Chapter 4). The data were analysed. After that, a group of fifty-five participants (fifty-one were analysed) was recruited for this experiment with decompensating heterophoria and compromised stereoacuity. The participants met the inclusion criteria (Table 3) and underwent a complete eye examination described in Chapter 3 (First appointment) and according to the Protocol (Chapter 3). The second appointment was held four to six weeks later ± 3 days and took up to thirty minutes. The appointment included measuring the relieving prism according to Sheard's Criterion and FD. The third appointment was held four to six weeks later ± 3 days and took up to thirty minutes, and the fourth appointment was held four to six weeks later ± 3 days (see 2.8).

Two amounts of compensating prisms were calculated. One prism is according to the SPC (see Chapter 4), and the other is according to the FD (see Chapter 5). The prism amount that contributed to no slip of the Nonius lines on the Mallett Unit referred to a relieving prism prescribed according to the FD. Two pairs of spectacle corrections using the same frame (model and colour) were made, and a Fresnel prism was glued on the back surface of the lens in front of the non-dominant eye according to the abovementioned criteria. The participant was provided with one of the pairs in a randomised, double-blind, cross-over manner (See Chapter 3).

The participants were asked to wear the spectacle correction on an ongoing basis for one and a half months. The third appointment was held one and a half months later, ± 3 days, and the prismatic correction was switched. The participants were asked to use the pair of glasses they got at the third appointment for one and a half months. At the end of each period, they were asked to fill in a modified CISS, which was also taken at the baseline. The third and fourth appointments were performed according to the Protocol (Chapter 3), and the methodology was the same as described in Chapter 3 (The Third and Fourth appointments). The randomisation, appointment timing, PAT, and dispensing methods were described in Chapter 3.

This experiment showed that FD provides a lower prism than the SPC and higher than Sheard's Criterion; however, the effect on symptom relief was not assessed. The question was if the FD prism was sufficient to relieve symptoms or if a stronger prism provided by the SPC was needed.

5.3. Results

5.3.1. The Participants

Fifty-five participants were recruited. Four participants were lost to follow-up, and fifty-one were analysed. The mean age of the participants was 30.1, ±7.64 years old. Of the 51 subjects, 27 (53.1 %) were female and 24 (46.9 %) were males. All 51 subjects underwent all the examinations (see Chapter 3). All of the participants met the inclusion criteria (Table 3).

5.3.2. Stereoacuity Results

Stereoacuity was measured with no relieving prism at the baseline, with prism prescribed according to FD and SPC after an adaptation period of six weeks l ± 3 days using Titmus and TNO. Table 17 demonstrates the measurement results. At the baseline, TNO was more compromised than Titmus, and both stereotests were compromised at a greater amount than with both relieving prisms. This means that relieving prism contributed to a higher stereoacuity.

Figure 9 demonstrates a trend of increasing stereoacuity with increasing relieving prism measured with Titmus and TNO. The stereo was measured at a different appointment, with no relieving prism, with a relieving prism prescribed according to FD and a prism prescribed according to the SPC. The SPC contributed to a higher stereoacuity for both Titmus and TNO. However, both prism values contributed to a comparable stereoacuity on both tests. Shapiro-Wilk demonstrated that the data were not normally distributed (Tables 20 and 21).

Table 20: Shapiro-Wilk results for stereoacuity tests measured in different conditions.				
Stereotest and measurement condition	Statistic	df	p	Outcome
Titmus with no prism	0.807	51	<0.001	The data are not normally distributed
TNO with no prism	0.839	51	<0.001	The data are not normally distributed
Titmus with FD Prism	0.753	51	<0.001	The data are not normally distributed
TNO with FD Prism	0.787	51	<0.001	The data are not normally distributed
Titmus with SPC	0.619	51	<0.001	The data are not normally distributed
TNO with SPC	0.751	51	<0.001	The data are not normally distributed

Table 20: *Demonstrates that stereoacuity measured in different conditions provided non-normalized data using the Shapiro-Wilk test.*

Since the data were not normally distributed, nonparametric tests were performed. Friedman test showed a statistically significant difference (N=51, Chi-square=195.639, df=5, p<0.001) in the stereoacuity mean, and the Wilcoxon Signed Rank test showed a significant difference between each stereoacuity mean except for the mean stereoacuity measured using Titmus with SPC and stereoacuity measured using TNO with SPC (Table 21).

Table 21: Stereoacuity mean measured with TNO and Titmus stereotests with no prism correction, with relieving prism prescribed according to FD and with prism according to the SPC comparison using Wilcoxon Signed Rank test				
Stereotest and measurement condition	Stereotest and measurement condition	z	p	Outcome
Baseline Titmus	Baseline TNO	-6.086	<0.001	Statistically significant
Baseline Titmus	Titmus with FD	-6.160	<0.001	Statistically significant
Baseline Titmus	TNO with FD	-6.161	<0.001	Statistically significant
Baseline Titmus	Titmus with SPC	-6.228	<0.001	Statistically significant
Baseline Titmus	TNO with SPC	-6.164	<0.001	Statistically significant
Baseline TNO	Titmus with FD	-6.227	<0.001	Statistically significant
Baseline TNO	TNO with FD	-6.226	<0.001	Statistically significant
Baseline TNO	Titmus with SPC	-6.255	<0.001	Statistically significant
Baseline TNO	TNO with SPC	-6.233	<0.001	Statistically significant
Titmus with FD	TNO with FD	-0.985	0.324	Not statistically significant
Titmus with FD	Titmus with SPC	-4.105	<0.001	Statistically significant
Titmus with FD	TNO with SPC	-2.424	0.015	Statistically significant
TNO with FD	Titmus with SPC	-2.547	0.011	Statistically significant
TNO with FD	TNO with SPC	-3.663	<0.001	Statistically significant
Titmus with SPC	TNO with SPC	-1.100	0.271	Not statistically significant

Table 21: *The mean stereoacuity measured with SPC using Titmus and TNO was not statistically significantly different (p=0.271), and the mean stereoacuity measured with FD using Titmus and TNO was not statistically significantly different (p=0.324).*

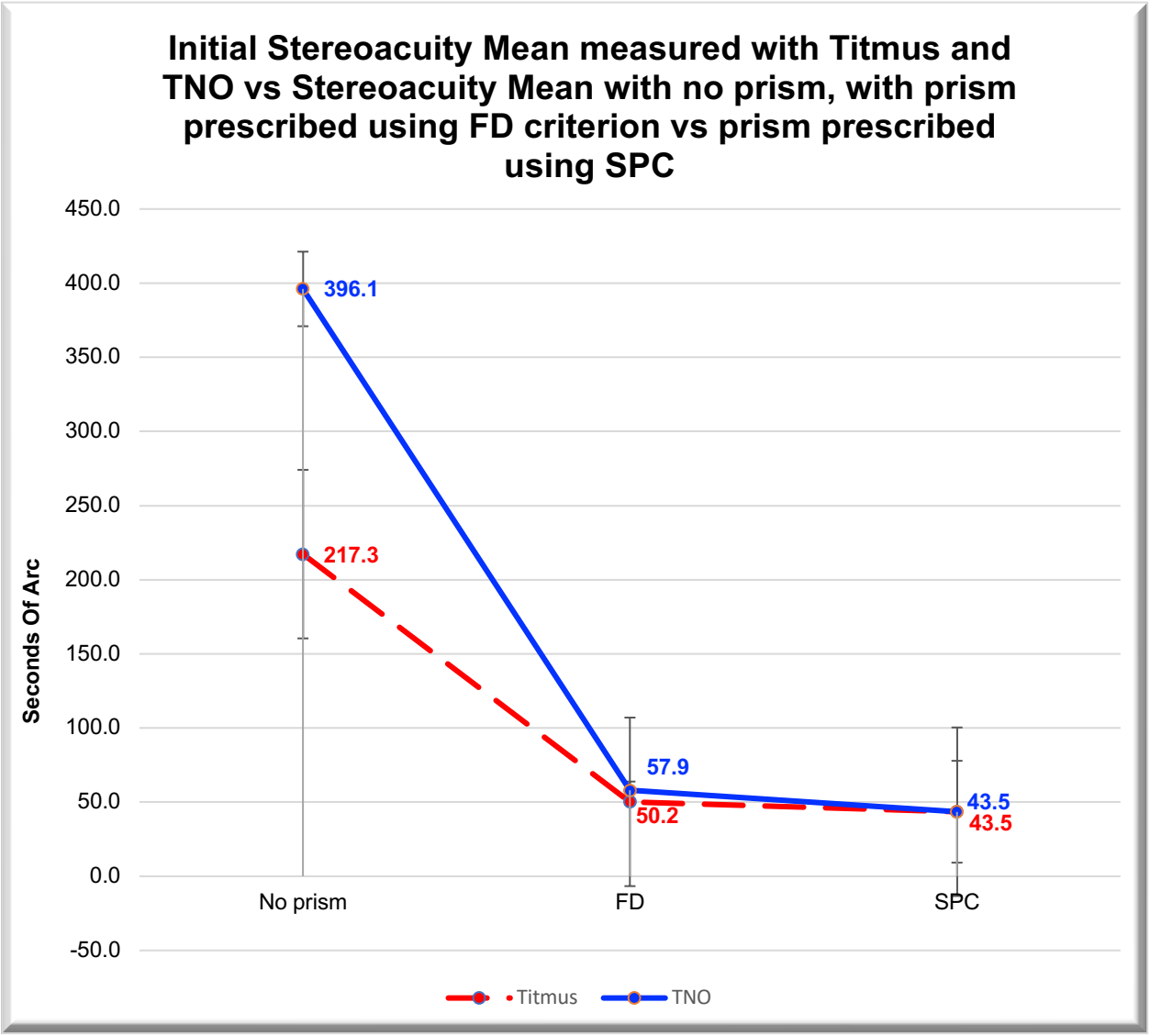


Figure 9: *The graph shows the improvement of stereopsis with relieving prism. Between Sheard's Criterion and stereopsis, Titmus was less affected by the difference in the amount of prism used to relieve it. However, TNO was more affected by those changes, being more compromised with no prism. Both stereotests were less compromised with FD and were virtually normal with SPC. The error bars represent the Standard Deviation of the mean.*

With an increase in the prismatic component, stereoscopic vision improves. This effect was more pronounced with TNO (Figure 9). Stereoacuity was measured at the baseline and between either stereoacuities measured with relieving prisms, prescribed according to FD and the SPC. There was a statistically significant difference between stereoacuity means measured at the baseline between the relieving prism. Both means at the baseline were significantly different from each other measurements, but TNO at

the baseline was the most compromised, indicating that TNO was more affected in heterophoria decompensation. However, stereoacuity with both prisms was no statistical difference on both stereotests.

SPC gave better stereo than the FD. Titmus and TNO gave a comparable stereoacuity with SPC; both provided a relatively good stereoacuity. With the FD prism, both stereotest results also had no statistical difference. However, SPC provided an additional prism compared to FD, resulting in a statistically significant higher stereoacuity on either Titmus or TNO. It means that the extra prism provided by SPC improved stereoacuity further. Therefore, it improved the state of compensation further, suggesting that an extra prism provided by SPC was beneficial over FD.

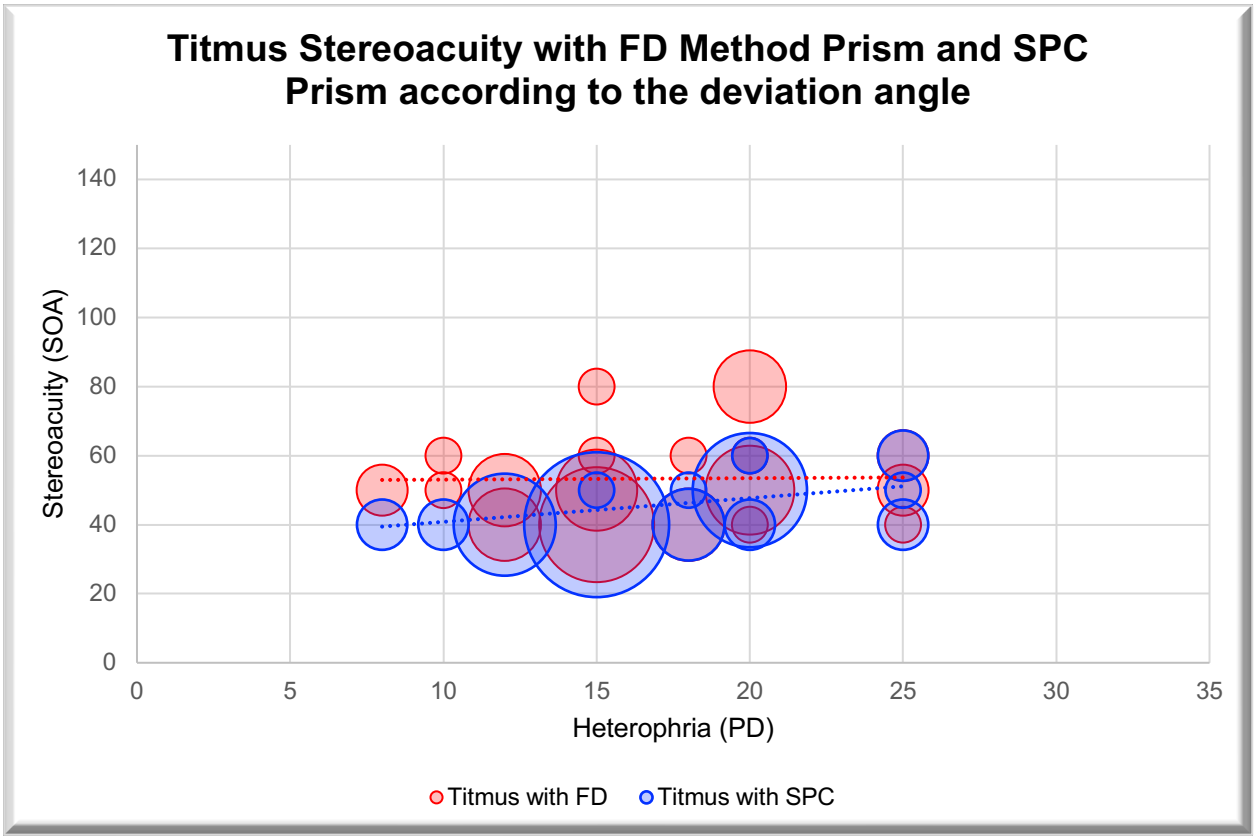


Figure 10: *Scatterplot showing that in 54.9% (28 cases), stereoacuity was the same with FD and SPC measured with Titmus.*

Figures 10 demonstrate that SPC contributed to a greater stereoacuity than the FD method using Titmus in less than half the cases (22 cases, 43.1%). In 54.9% (28 cases), stereoacuity was the same measured with FD and SPC; in 1 case (2%), SPC contributed to a more compromised stereoacuity than FD It means that TNO was more

readily compromised than Titmus with decompensating heterophoria; which is in agreement with the pilot study (Rinsky, 2017).

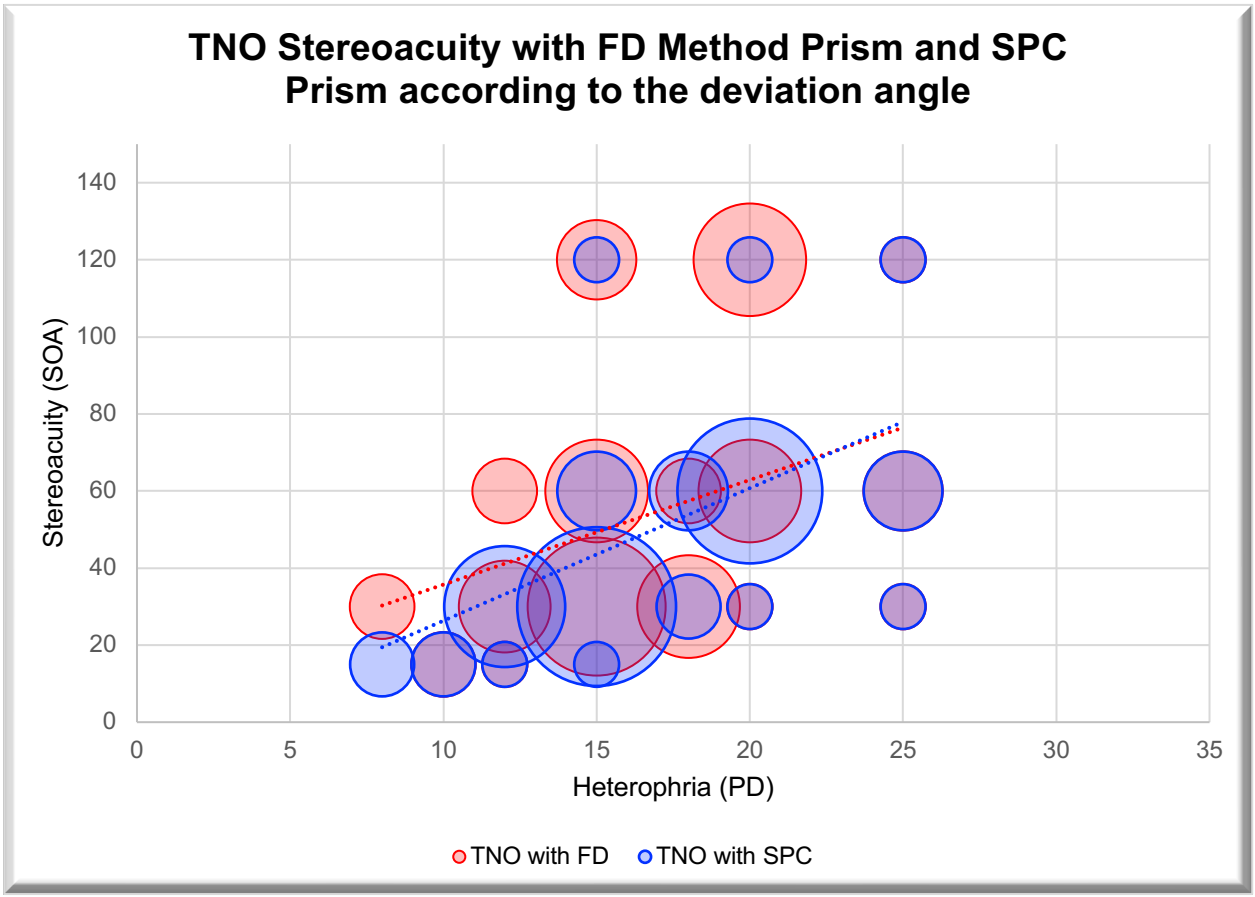


Figure 11: *Scatterplot showing that in 66.7% (34 cases), stereoacuity was the same with FD and SPC with TNO. However, in 33.3% (17 cases), TNO improved with SPC compared to FD. There was no single case where SPC contributed to a more compromised stereoacuity than FD.*

Figure 11 demonstrates that in 33.3% (17 cases), SPC contributed to a higher stereoacuity measured with TNO than FD. There were no cases where TNO contributed to a more compromised stereoacuity than FD, and in 66.7% (34 cases), stereoacuity was the same with both prisms. This means that SPC was beneficial in almost a third of cases compared to FD.

As the heterophoria was getting higher, the corrected stereo was getting worse. It means that there is room for further improvement in subjects with a higher level of decompensated heterophoria. Possibly, those subjects need an even higher prism than SPC provided. On the other hand, those subjects may not be capable of a better

stereopsis since their binocular vision system is compromised and can not generate a better stereopsis in the first place. This can be investigated in further work.

5.3.3. Prism Results

The mean relieving prism calculated according to the FD Method was (9.67, ±2.94 PD) lower than provided by SPC (13.03, ± 5.03 PD) (Figure 13). Shapiro-Wilk demonstrated that prism amounts gained with FD were not normally distributed (Statistic=.937, fd=51, p=0.009) and prism amounts gained with SPC were normally distributed (Statistic=.956, fd=51, p=0.054). The Wilcoxon Signed Rank test showed a significant difference between the prism mean calculated according to FD and the SPC (z=-4.744, p<0.001).

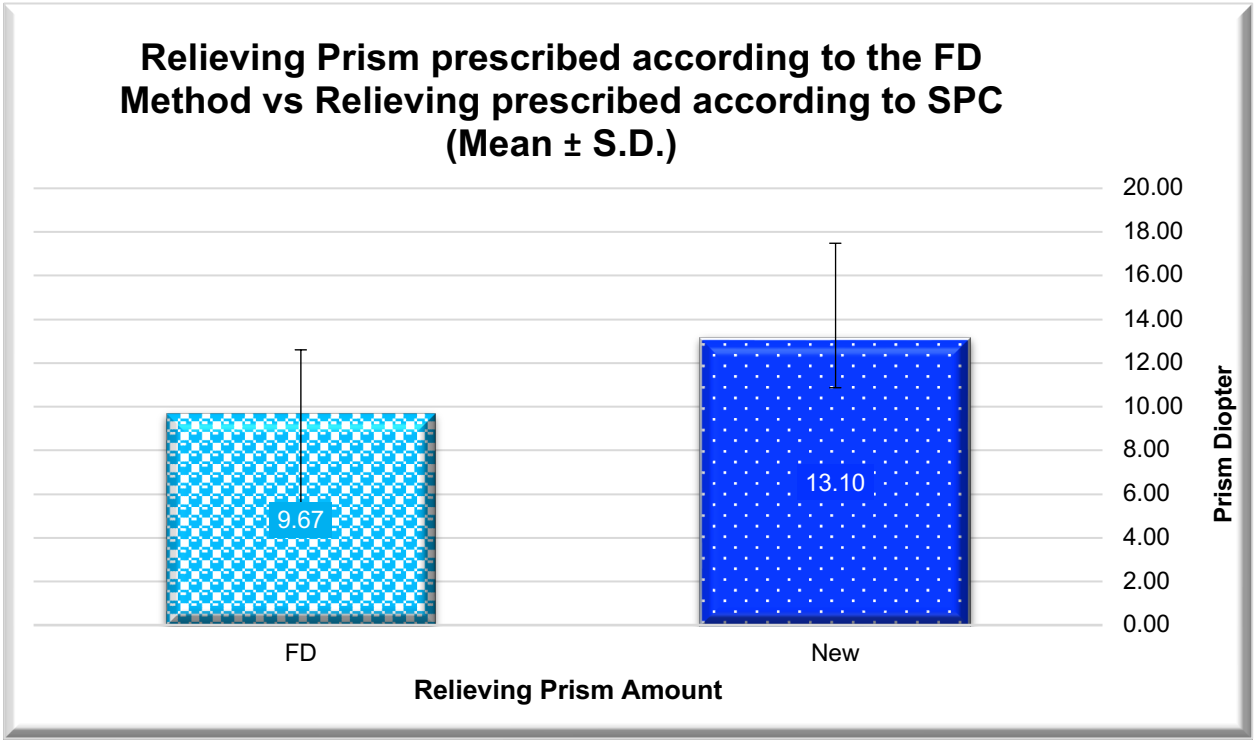


Figure 12: *The graph shows that the relieving provided by the SPC (13.03, ±5.03) was significantly higher than that provided by the FD Method (9.67, ±2.94) with p<0.05. The error bars represent the Standard Deviation of the mean.*

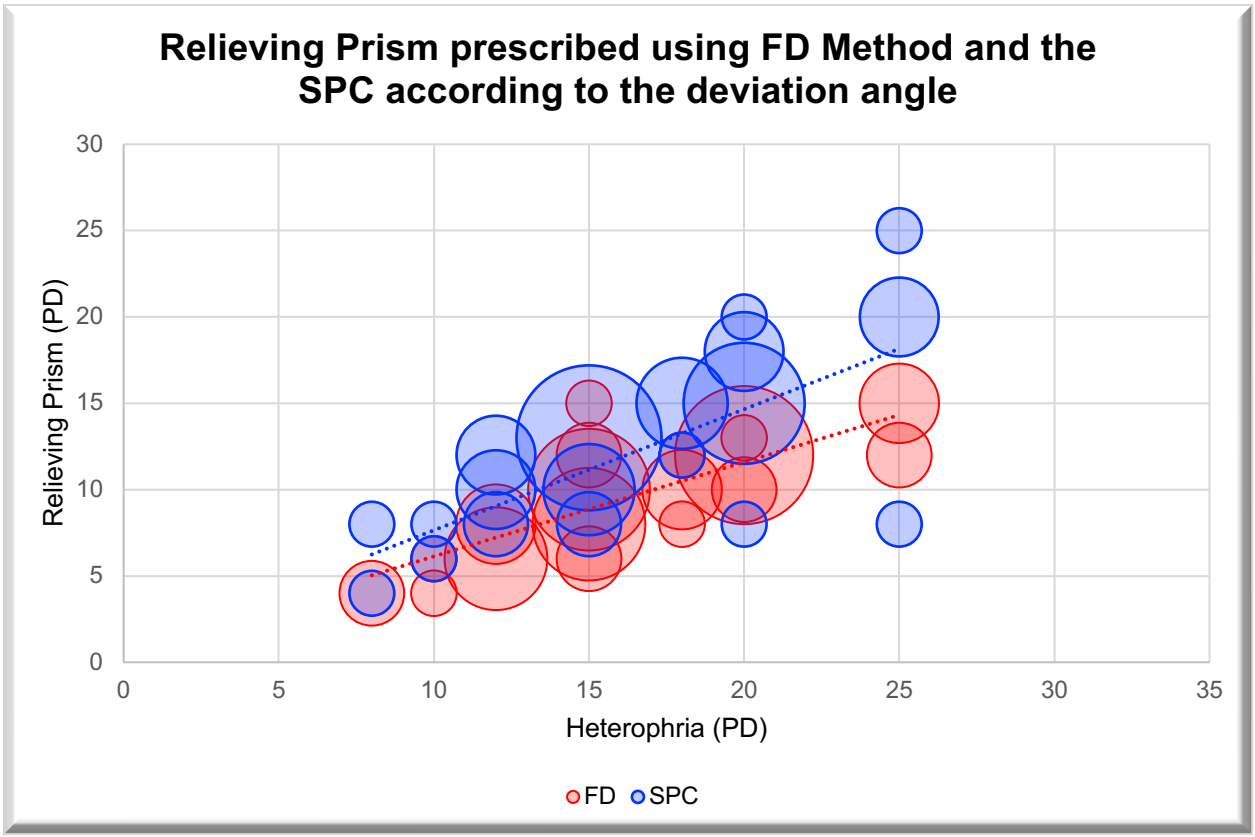


Figure 13: *Scatterplot showing that the relieving prism prescribed according to SPC was higher in the vast majority of the cases, 84% (32 cases). In 13.7%, the prism value was the same, and in 1.9% (1 case), SPC contributed to a lower prism than FD.*

Figures 13,14 demonstrate the distribution of the relieving prism prescribed using the FD method and the SPC. The SPC contributed to a higher prism amount in the vast majority of the cases, in 84.4% (43 cases). The prism value was the same in 13.7% (7 cases), and in one case (1.9%), FD provided a higher prism compared to SPC.

The FD prism calculation method provides a higher prism than Sherard's Criterion, and the SPC consistently gives a higher prism value than FD (Chapters 4 and 5). This was true for the vast majority of the cases but not in every single one, as it was with Sheard's relieving prism experiment (Chapter 4). For some subjects, the FD provided a higher amount of prism than SPC. The reason for that may be noise since the number of participants was limited. However, future work is needed in order to investigate this aspect in more detail.

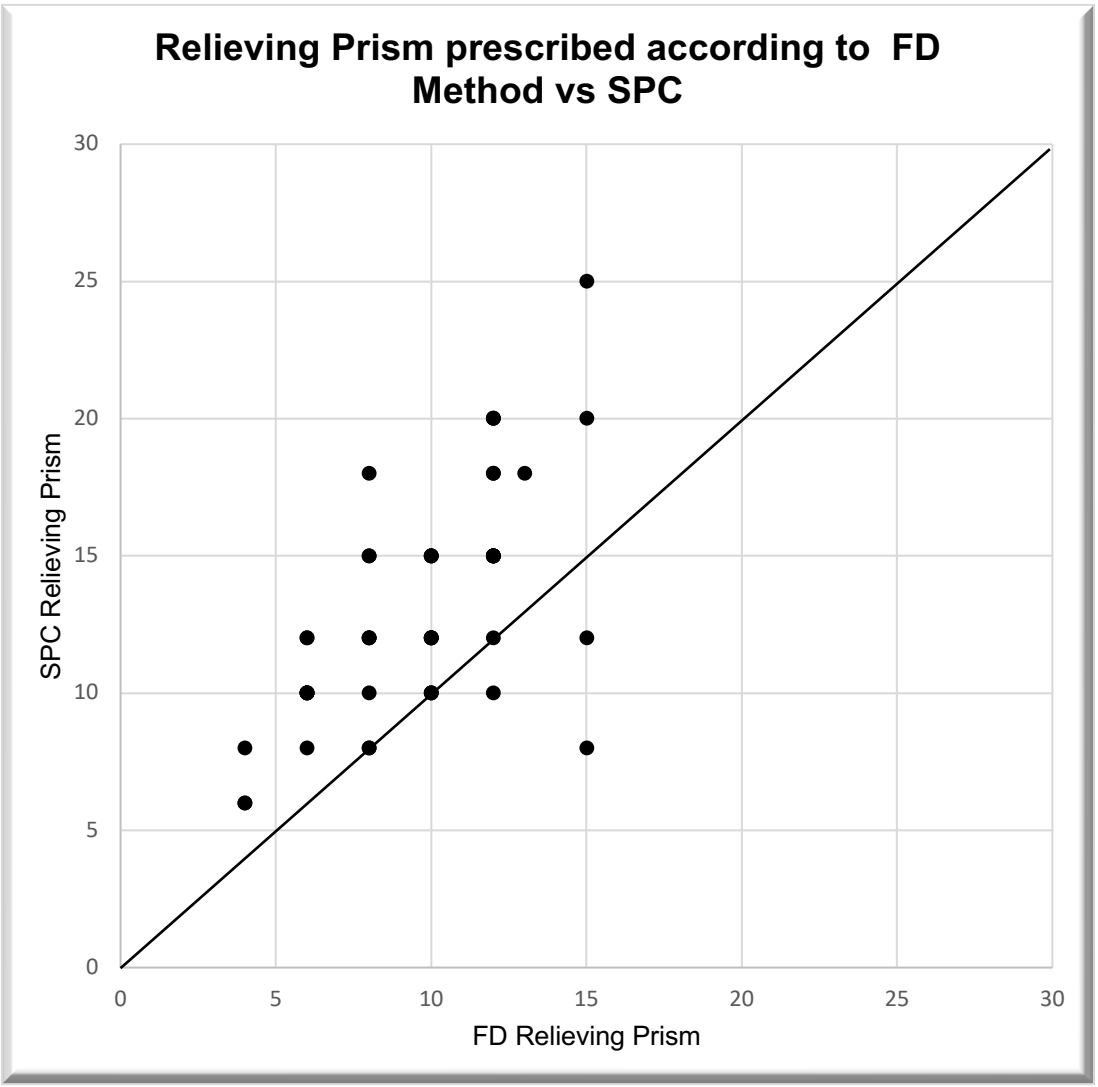


Figure 14: *Scatterplot showing that the relieving prism distribution prescribed according to the SPC was higher than that provided by FD Method in the vast majority of the cases.*

5.3.4. Questionnaire Results

The baseline modified CISS mean score (taken at the first appointment) was significantly more compromised (40.88, ±6.50) compared to that taken after the participants were wearing prismatic glasses prescribed according to the FD Method (27.02, ± 6.63). The CISS mean improved even harder with SPC (21.96, ±5.03) (Table 22). This means that SPC provided better symptom relief than the FD prism.

Table 22: Modified CISS mean ± S.D. taken at the baseline with no relieving prism, with prism prescribed according to the FD Method and with prism prescribed according to the SPC		
The appointment	Mean	SD
Initial mean modified CISS questionnaire	40.88*	6.50
Mean modified CISS questionnaire with prism prescribed according to the FD Method	27.02*	6.63
Mean modified CISS questionnaire with prism prescribed according to the SPC	21.96*	5.03

Table 22: *The table shows that the FD Method contributed to symptom relief compared to what was measured at the baseline. SPC provided an even greater symptom relief Criterion. * means that there was a statistically significant difference.*

The participants filled in the modified CISS at the baseline and after both periods of prismatic correction use, prescribed according to the SPC and FD (Figure 15). The baseline (initial) modified CISS questionnaire mean results were 40.88, ±6.5. The FD prism provided significant symptom relief (27.02, ± 6.56) compared to the baseline, and even greater relief was obtained after the participants were wearing prismatic glasses prescribed according to the SPC (21.96, ± 4.98) (Figure 16). Shapiro-Wilk test showed that the questionnaires provided normally distributed data (Initial questionnaire Statistic =0.986, df=51, p=0.798; FD questionnaire Statistic =0.964, df=51, p=0.123; SPC questionnaire Statistic =0.985, df=51, p=0.783). Repeated Measures ANOVA showed a statistically significant difference with a very low p-value ($p<0.001$). The value of the test statistics was $F=131.750$ with a degree of freedom 2. A Tukey post-hoc test was performed to determine the significant difference between each test. The Tukey test showed a significant difference between each questionnaire means ($p>0.001$).

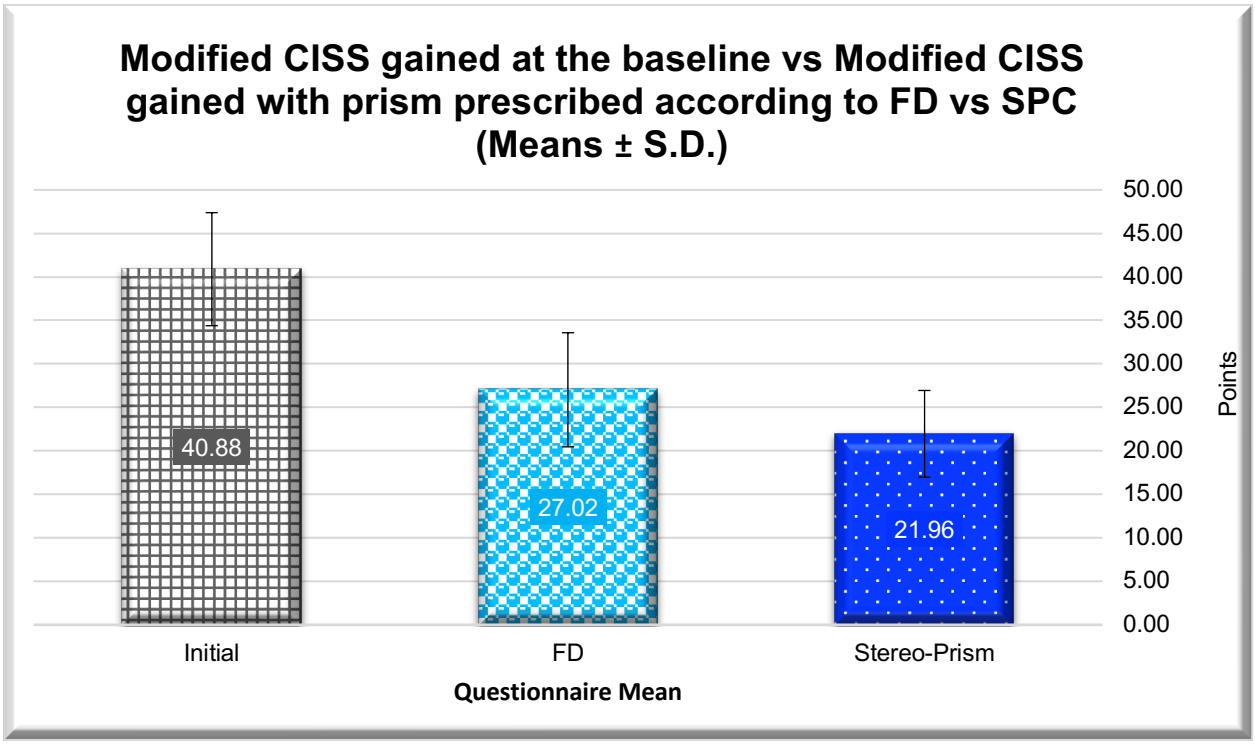


Figure 15: *The graph shows that the SPC contributed to a significantly greater relief of symptoms (21.96, ±4.98) than FD (27.02, ±6.56) with p<0.05. FD contributed to significant relief of symptoms relative to the initial level with p <0.05 (40.88, ±6.50). The error bars represent the Standard Deviation of the mean.*

5.4. Comparison of the Chapter 4 Cohort and Chapter 5 Cohort

The first cohort of participants used a prismatic correction prescribed according to Sheard's Criterion and SPC, and the results were compared (Chapter 4). The second cohort of participants used a prismatic correction prescribed according to the FD method and SPC (this experiment, Chapter 5), and the results were compared as well. Since the group of subjects participated in Sheard's experiment (Chapter 4) and FD experiment (Chapter 5) the cohort's data were compared to ensure that the two cohorts had the same initial data and that the results of the two experiments could be compared.

5.4.1. Relieving Prism Comparison

According to Sheard's Criterion FD and SPC, the mean relieving prism was calculated using the data gained in Sheard's experiment (Chapter 4). The mean

relieving prism calculated according to Sheard's Criterion (7.3, ±3.9 PD) was lower than the relieving prism calculated according to the FD (9.91, ±3.24 PD), and the prism according to the SPC was 13±5PD was the highest (Figure 16). As was shown previously (section 4.3.3) the prism mean calculated according to Sheard's was significantly lower than prism mean calculated according to SPC. The Related-Samoles Wilcoxon Signed Rank test demonstrated that the FD prism was significantly higher than Sheard's prism (N=69, Statistic=-4.564, p<0.001) and was significantly lower than the SPC prism (N=69, Statistic=4.996, p<0.001). The data were obtained among participants recruited for Sheard's experiment (The Relieving Prism Prescribing, According to Sheard's versus the SPC experiment) (Chapter 4).

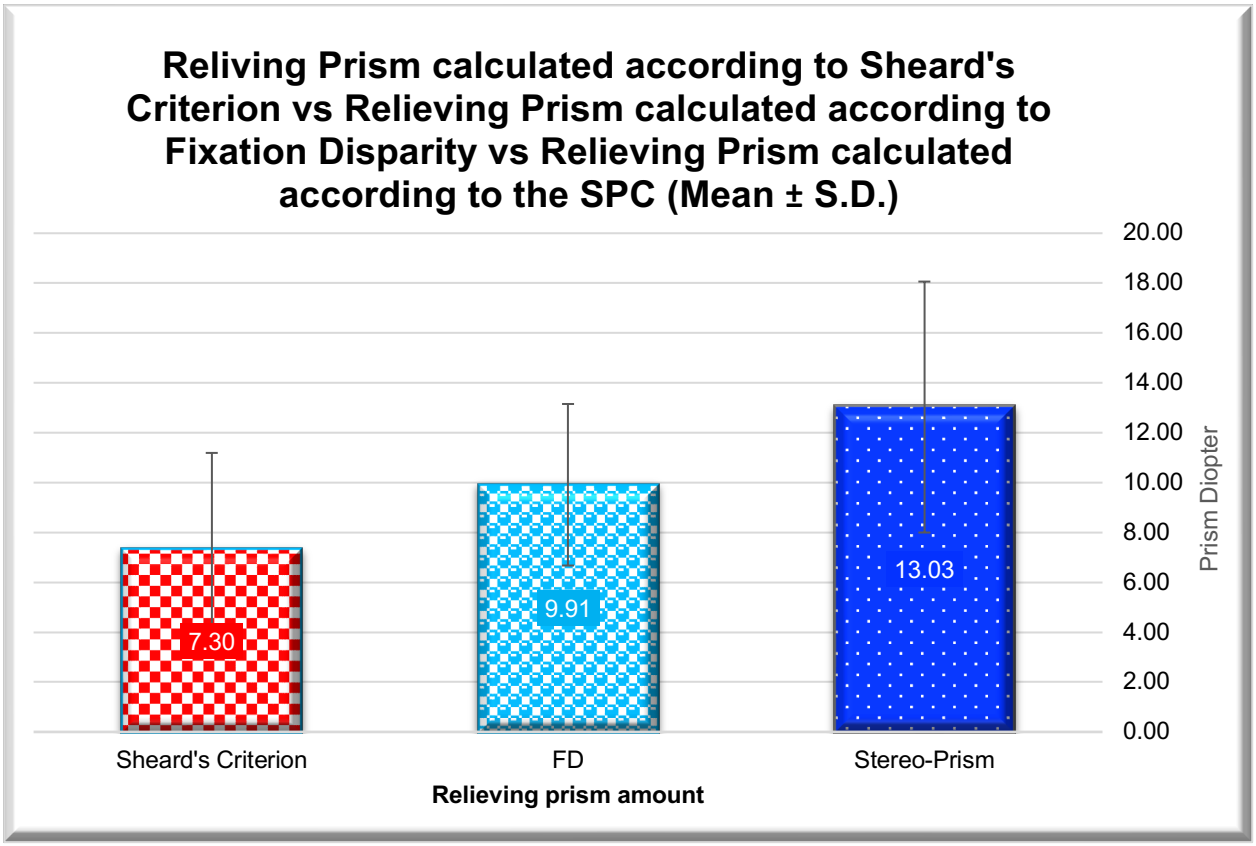


Figure 16: *The graph shows that the relieving prism calculated according to the SPC (13.03, ±5.03) was significantly (p<0.05) higher than the prism calculated according to FD (9.91, ±3.24), which was significantly higher (p<0.05) than Sheard's Criterion (7.3 ±3.89). The error bars represent the Standard Deviation of the mean.*

The mean relieving prism prescribed according to the FD taken in Sheard's experiment (9.91, ±3.24 PD) was comparable to the FD prism taken in the FD experiment (9.67, ±2.94 PD), this experiment. The mean relieving prism prescribed

according to the SPC taken in Sheard's experiment (13.03, ±5.03 PD) was also comparable to that was taken in the FD experiment (13.1, ±4.39 PD) using SPC (Figure 17). In both experiments, SPC provided a significantly higher prism than FD. This means that the data obtained from the experiments of Sheard's cohort and FD can be compared with each other, and SPC provides a higher prism value.

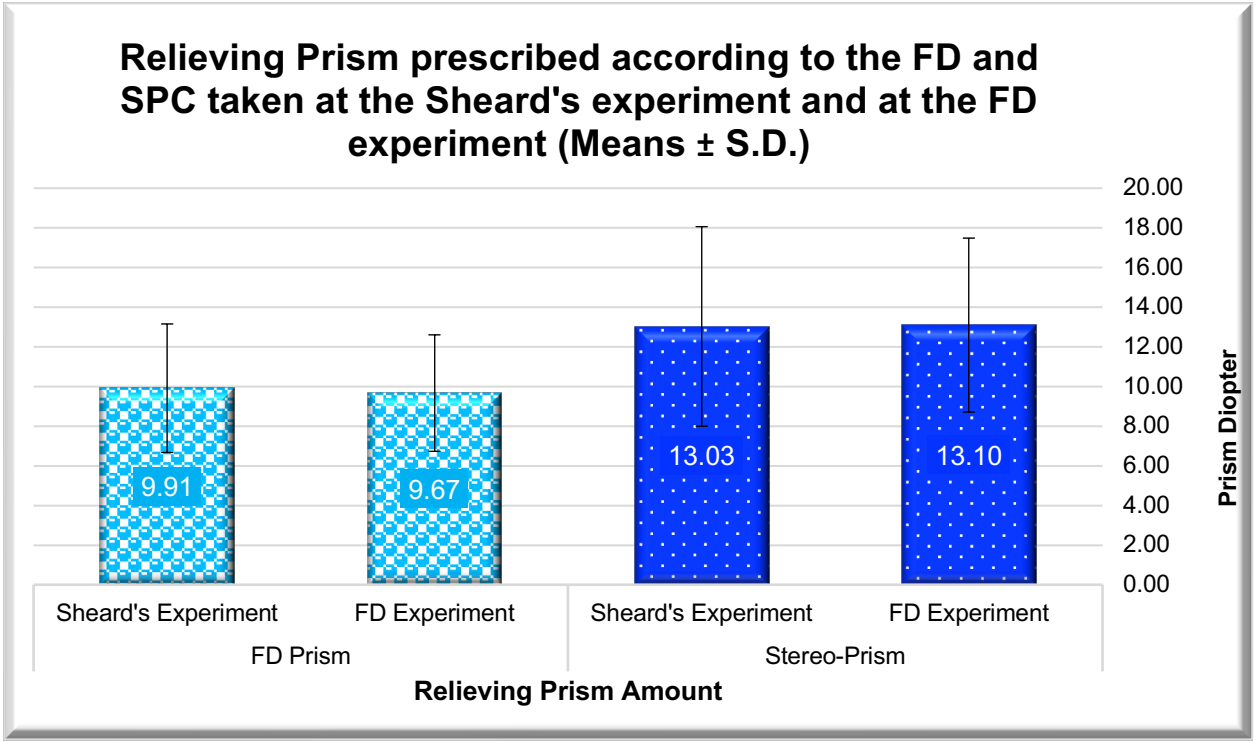


Figure 17: *The graph shows that the relieving prism prescribed according to FD at Sheard's experiment (9.91, ±3.24 PD) and FD experiment (9.67, ±2.94 PD) was comparable ($p>0.05$) as well as the relieving prism prescribed according to the SPC at the Sheard's experiment (13.03, ±5.03 PD) and FD experiment (13.10, ±4.39 PD) $p>0.05$. Moreover, SPC provided a significantly higher prism compared to FD ($p<0.05$) in both experiments. The error bars represent the Standard Deviation of the mean.*

The Shapiro-Wilk test showed that the data were normally distributed (FD prism Sheard's experiment Statistic=0.955, df-51, p=0.051; FD prism FD experiment Statistic=0.937, df-51, p=0.09; SPC prism Sheard's experiment Statistic=0.950, df-51, p=0.03; SPC prism FD experiment Statistic=0.956, df-51, p=0.05). To compare the FD mean gained at Sheard's experiment with the FD mean gained at the FD experiment, 51 results were randomly chosen from the data gained at the FD experiment, which was compared. The independent T-Test showed no significant

difference between the means (t=0.773, fd=50, p=.443). To compare the Sheard's relieving prism mean gained at Sheard's experiment with Sheard's relieving prism mean gained at the FD experiment, 51 results were randomly chosen from the data gained at the FD experiment, which was compared. The independent T-Test showed no significant difference between the means (t=0.328, fd=50, p=0.744).

5.4.2. Modified CISS Comparison

To ensure that the participants in Sheard's experiment, described in Chapter 4, and the FD experiment (this experiment) had the same initial data, the modified CISS mean gained in Sheard's and FD experiments was compared (Table 23).

Table 23: Modified CISS mean ± S.D. taken at the baseline with no relieving prism, with prism prescribed according to Sheard's Criterion and with prism prescribed according to the SPC

	Initial mean modified CISS questionnaire		**Questionnaire with the Stere-Prism Criterion**	
	FD Experiment	Sheard's Experiment	FD Experiment	Sheard's Experiment
Modified CISS mean	40.88*	42.00*	21.96*	21.84*
Modified CISS SD	6.50	6.99	5.03	0.00

Table 23: *The table represents the modified CISS questionnaire mean taken at the baseline with both relieving prisms, which was comparable as well as with SPC.* means that there was a statistically significant difference.*

As Table 19 shows, SPC contributed to greater symptom relief than FD in Sheard's experiment and the FD experiment. The modified CISS at the baseline and with the SPC prism was comparable in both experiments.

Figure 18 demonstrates that the mean modified CISS taken at Sheard's experiment baseline (42.00, ±6.99 SOA) (Chapter 4) was similar to the mean modified CISS taken at the FD experiment baseline (40.88, ± 6.50 SOA) (p>0.05). The mean

modified CISS taken after the participants used a prismatic correction prescribed according to the SPC in Sheard's experiment (21.84, ± 6.5 SOA) was similar to what was taken in the FD experiment (21.96, ± 5.03 SOA) ($p>0.05$). The CISS mean taken with SPC was significantly higher in both experiments. It means that SPC provided a greater symptom relief compared, and the groups can be compared. This means that the two cohorts of participants, the Sheard's and FD, can be compared.

A comparison between the modified CISS questionnaire's means was performed using the Repeated Measures ANOVA test. ANOVA showed a statistically significant difference with a very low p-value ($p<0.001$). The value of the test statistics was $F=190.292$ with a degree of freedom 3. A Tukey post-hoc test was performed to determine the significant difference between each test. The Tukey test showed no significant difference between the questionnaire means taken in Sheard's experiment and the FD experiment baseline ($p=0.778$), and there was no difference between questionnaire means after the participants used prismatic correction prescribed according to the SPC ($p=1.0$). Prism prescribed at the baseline was significantly different from what was prescribed with prism with both criteria ($p<0.05$).

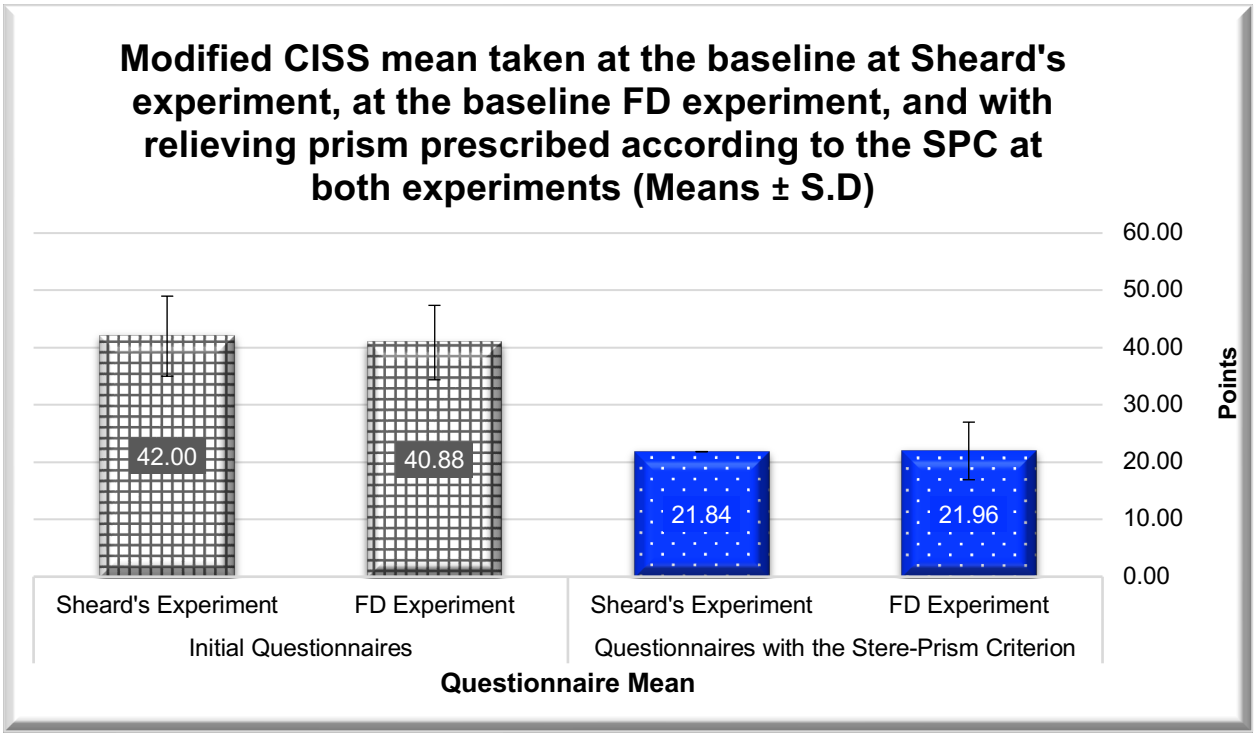


Figure 18: *The graph shows that the modified CISS mean gained at the baseline at Sheard's experiment (42.00, ±6.99) was similar to what was obtained in the FD experiment (42.00, ±6.99) $p>0.05$. There was no significant difference between the*

CISS mean gained with the SPC at Sheard's experiment (21.84, ±6.) and FD experiment (21.96, ±5.3) p>0.05. The relief of symptoms was significantly higher (p>0.05) with SPC prism in both experiments in comparison to the baseline.

The data obtained from the experiments of Sheard's group and FD can be compared, and SPC provided greater symptom relief than the FD method. *The error bars represent the Standard Deviation of the mean.*

5.5. Discussion

It was shown that FD provided a higher relieving prism than Sheard's Criterion but lower than the SPC. Relieving prism prescribed according to SPC was higher in the vast majority of the cases, 84% (32 cases).

The FD prism calculation does not consider the stereoacuity, which indicates the operability of the binocular system. Hence, stereoacuity may provide a more precise prism calculation method. Abd Manan et al. (2001) demonstrated a significantly reduced stereoacuity measured with TNO among participants with FD compared with those without FD. A prismatic prescription, according to FD, statistically improved stereoacuity.

Thirty optometry students with normal binocular vision participated in Kundart's and Saad's (2016) study. The author artificially reduced the stereopsis of the participants and measured it with and without prismatic correction. There were two groups, one with a placebo prism correction. The prism was obtained by a technique developed by the author (i.e., "comfortable prisms)": the prism was obtained according to the FD, provided a minimal binocular blur and visual discomfort and gave the best stereoacuity. The results showed that the "comfortable prism" provided no statistically significant near stereoacuity improvement compared to the placebo group. Moreover, Otto (2008a) found no correlation between the prism prescribed according to the FD and the "comfortable" prism.

Different results were demonstrated by Pang et al. (2012). The author ran a study where twenty-nine symptomatic CI presbyopes were given two progressive addition spectacles in a double-blind, randomised sequence. The prism was prescribed

according to the FD in one pair of glasses, while the other pair served as a placebo. The participants were asked to wear the glasses for three weeks. The results showed a statistically significant symptom reduction (CISS score improvement) with prismatic correction compared to placebo. The results of Nabovati et al. (2020) agree with the results of Pang et al. (2012). The authors randomly divided sixty-four young adults aged 18-39 with CI into two groups. One group was assigned a prism (the prism amount was calculated using the motor approach) and the other with placebo spectacles. The experiment's outcome was that the mean CISS score was statistically significantly lower in the prismatic group compared to the placebo group. In 2009, Teitelbaum, Pang and Krall (2009) evaluated the effect of prismatic correction (prescribed according to the FD analysis) on alleviating vision-related symptoms of presbyopic adults with CI. According to the results, prismatic spectacles effectively relieved the patient's symptoms.

Another study that supports applying the prism prescribing method based on the FD was conducted by O'Leary and Evans (2006). It included fifty-eight participants with exophoria. The results demonstrated a visual performance improvement with an aligning prism instead of no prismatic correction. The reason for such results could be that the authors used the Wilkins Rate of Reading Test (WRRT). The WRRT was developed to evaluate the effect of coloured filters on reading in children with reading difficulties but not the symptoms.

Paediatric Eye Disease Investigator Group ran a pilot randomised trial in 2023 to compare the prism treatment strategy versus refractive correction alone for children with intermittent exotropia. The amount of prism was forty per cent of the deviation angle, which did not provide better satisfaction.

The group of participants recruited for this experiment had a modified CISS mean at the baseline comparable to that of the participants from Sheard’s experiment, discussed in Chapter 4. The modified CISS mean was also comparable after participants used a relieving prism prescribed according to the SPC. Moreover, the relieving prism mean calculated according to the SPC was significantly higher than that calculated according to FD in both experiments. This means that the findings of two cohorts of participants in the two experiments can be compared. This experiment showed that the relieving prism prescribed according to the SPC is beneficial compared to the FD method. The relieving prism provided by the SPC was higher than that provided by FD, which contributed to greater symptom relief.

5.6. Conclusion

The FD prism calculation method provides a higher prism than Sherard's Criterion, and the SPC consistently gives a higher prism value than FD. This was true for the vast majority of the cases but not in every single one, as it was with Sheard's relieving prism experiment (Chapter 4). The SPC is more effective than the FD and Sheard criterion in relieving the symptoms of patients with decompensating heterophoria. However, the question arises whether symptoms are reduced sufficiently with the prism prescribed according to the SPC. Does the level of symptoms decrease to normal value?

SPC provided a higher prism value than the FD experiment. However, FD and SPC provided a higher local and global stereopsis compared to the baseline but with no statistically significant difference for both prism values. From the stereo point of view, FD and SPC provide virtually the same values. However, the mean level of symptoms was significantly lower with SPC than with FD prism. It means that even though the level of stereopsis is normal, the patient still can be symptomatic (see Chapter 6). This justifies giving the extra amount of prism using the SPC.

It can be concluded that comparing FD with SPC, the stereopsis provided by the relieving prism gained with the two methods was the same whether using Titmus or TNO, but the decrease of symptoms was greater with SPC. Therefore, the SPC is more beneficial than FD. Sheard's Criterion can be eliminated, but there is a need to look at the FD in more detail in future work since FD provides as high stereoacuity as SPC on Titmus and TNO.

There is a need to determine the "normal" modified CISS score. If the FD provides a relieving prism that brings the symptoms to a normal score, then there is no need to apply the SPC that provides a higher prism. However, if the prism provided by FD does not bring the symptoms to a normal value, then there is a justification for a higher prism provided by the SPC.

6. Decompensating Heterophoria with Normal Stereoacuity – Refining the TNO

6.1. Introduction

The SPC is based on the stereovision measurement using stereotests available on the market. These stereotests have certain measurement steps that contribute to the error of these measurements. A limited group of participants had a decompensated heterophoria, but their stereoacuity was normal. They reached 40 SOA for one of the stereotests: Frisby, Titmus, Ramdot, or TNO. Since this group did not meet the inclusion criterion (Table 3) except for stereoacuity, it was analysed as a separate group.

The approach in this research was that the SPC relieving prism Criterion was based on the stereoacuity measurement, which is a standard application that uses an available on-the-market clinical test. This research used TNO to prescribe relieving prism because it is a more affected than the local tests. The applied approach was to measure the minimum prism for maximum global stereoacuity. However, in the inclusion/exclusion criteria, both local and global stereotests were applied. The participant who passed the local test but failed a global one did not meet the inclusion criteria (Table 3). However, his/her stereoacuity may be reduced.

The question of this experiment is whether the new approach to stereoacuity measurement, doubling the viewing distance (see 2.10), will help identify reduced stereoacuity and whether a compensating prism will contribute to a higher stereoacuity. The hypothesis was that with a relieving prism, stereoacuity would increase, and this would mean that the use of an SPC prism prescribing criterion could be applied to this group of patients.

6.2. Methodology

The standard Titmus and TNO measuring distance is forty centimetres. This experiment doubled the measuring distance to make the stereopsis finer. This method should make the test more accurate, allowing it to measure stereoacuity better than the standard method allows for (see 3.10). It is less directly relevant to a near task.

Because of that the measurement should be performed at 40 cm. with finer steps of stereoacuity to further measure stereopsis. With doubling the measurement distance, the demand to convergence and accommodation reduces, and heterophoria decompensation status may be changed by that. However, extending the distance enables a finer TNO measurement, and the participants still remain heterophoria decompensating.

Six participants were recruited for this experiment.

Two sets of relieving prisms were calculated, one according to Sheard's Criterion and the other according to the SPC. The stereoacuity of the participants was measured with those two sets of prisms using Titmus and TNO tests at a viewing distance of forty and eighty centimetres. The tests were performed while the participants were wearing their habitual optical correction.

6.3. Results

6.3.1. The participants

The mean age of the participants was 30.5, ±6.53 years old. Of the six subjects, 4 (66.6 %) were female and 2 (33.4 %) were males. All six subjects underwent all the examinations. All participants had decompensated exo phoria at near with stereoacuity of at least 40 SOA on at least one of the stereotests: Frisby, Titmus, Randot, TNO (see Appendix 3 for the examination methodology). The inclusion criterion was that the participant should have reached 40 SOA on any of the stereotests. It means that in a TNO stereotest with no 40 SOA target, the inclusion criterion was that the participant had to pass the 30 SOA target.

6.3.2. Stereoacuity at 40 cm Results

Shapiro-Wilk test showed that stereoacuity measured with ether test was not normally distributed (Statistic=0.189, df=6, p=0.485; Randot Statistic=0.233, df=6, p=0.1414, TNO Statistic=0.312, df=6, p=0.051). The mean stereoacuity measured at 40 cm with TNO (180.00, ±161.00 SOA) was significantly more compromised than that was measured with Titmus (40, ±0 SOA) and with Randot (54.17, ±24.85). and with Frisby

(54.17, ±19.6.85 SOA) (Figure 19). Table 24 represents the comparison results between stereoacuity means using the Wilcoxon Signed Ranks test.

Table 24: Stereoacuity comparison results between stereoacuity means measured with Frisby, Titmus, Randot and TNO using Wilcoxon Signed Rank test

Stereo test	Stereo test	z	p	Outcome
TNO	Randot	-2.201	0.028	Statistically significant
TNO	Titmus	-2.214	0.027	Statistically significant
TNO	Frisby	-2.201	0.028	Statistically significant
Randot	Titmus	-1.146	0.144	Not statistically significant
Randot	Frisby	-0.143	0.893	Not statistically significant
Titmus	Frisby	-1.518	0.129	Not statistically significant

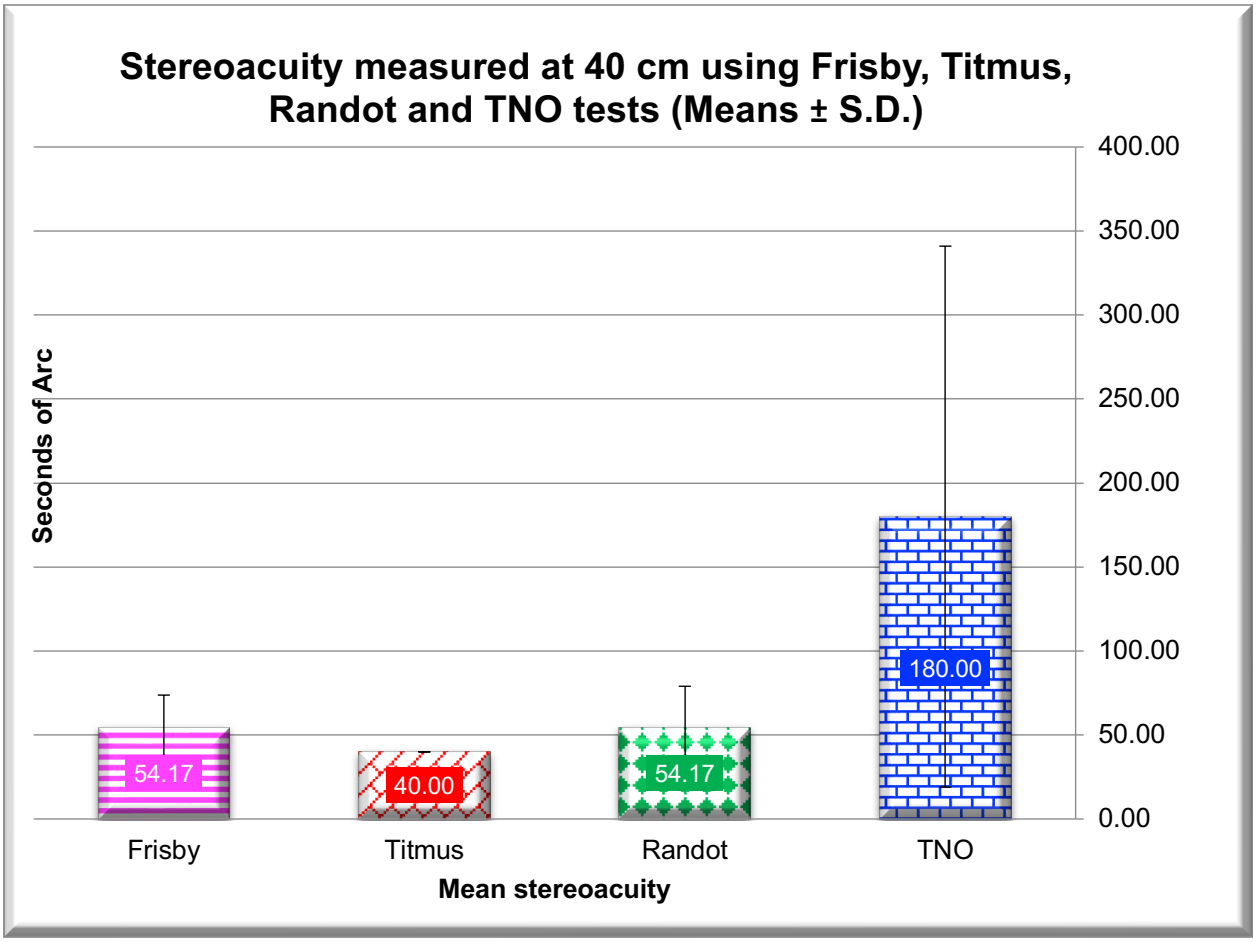


Figure 19: *The graph shows that stereoacuity measured with TNO (180, ±161 SOA) was significantly more compromised (p<0.05) than with Titmus (40, ±0 SOA). Stereoacuity measured with Titmus, Frisby (54.17, ±19.50 SOA) and Randot (54.17,*

±24.85 SOA) was not significantly different. The error bars represent the Standard Deviation of the mean.

2picking up the compensation deficit that the other tests are missing.

6.3.3. Stereoacuity at 80 cm Results

The mean stereoacuity was measured at 80 cm using Titmus (146.67, ±58.88 SOA) and using TNO (366.67 SOA) was statistically different (Figure 20). The Related Samples Wilcoxon Signed Rank test showed N=6, p=0.027.

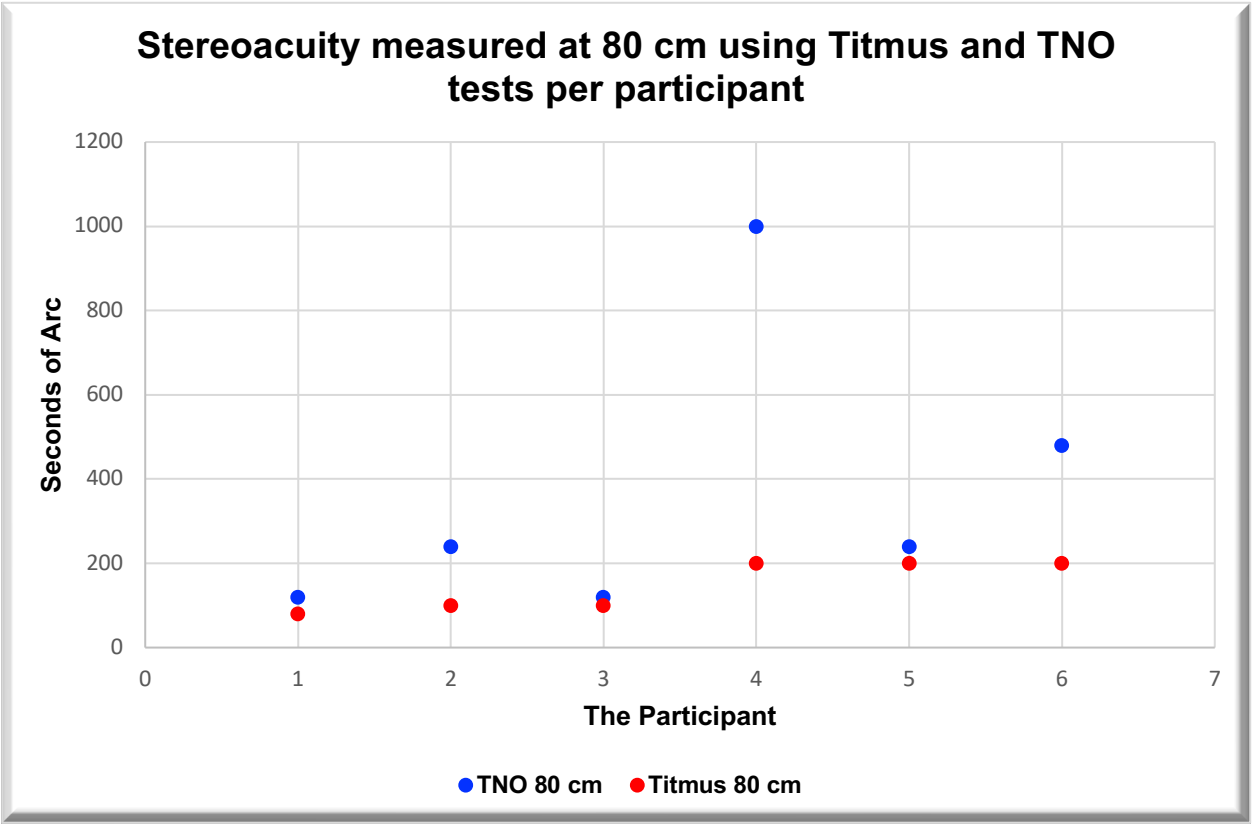


Figure 20: *The graph shows that the stereoacuity measured with TNO (mean 366.67,* ±336.97) *was more compromised than measured with Titmus (mean 146.67, ±58.88) but with no significant difference (p>0.05).*

6.3.4. Relieving prism calculation Results

The relieving prism calculated according to SPC (11, ± 3.74 PD) took the measurement at 80 cm. It was significantly higher compared to Sheard's Criterion (7.22,

±2.65 PD) (Figure 21). Shapiro-Wilk test showed that the data were normally distributed (Sheard's prism Statistic=0.889, df=6, =0.312; SPC prism Statistic=0.937, df=6, =0.634). The Paired-Sample T-test was used to compare the relieving prism means. The test showed a statistically significant difference ($p<0.05$; $t=-6.052$; $DF=5$).

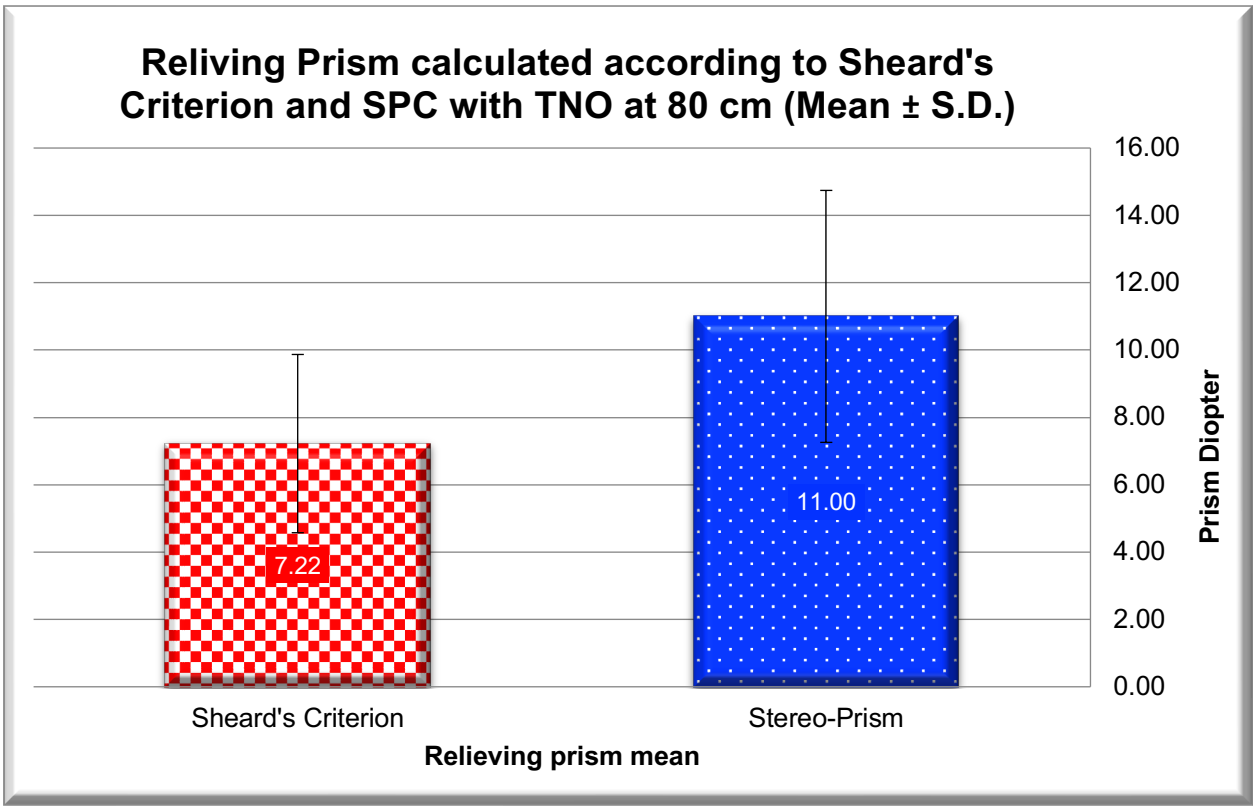


Figure 21: *The graph shows that the prism calculated according to SPC while TNO was at 80 cm (11.00, ±3.74) was significantly higher than the prism calculated according to Sheard's Criterion (7.22, ±2.65) with $p<0.05$. The error bars represent the Standard Deviation of the mean.*

6.3.5. Stereoacuity with relieving prism (Sheard's and SPC with TNO at 80 cm) Results

Stereoacuity using Titmus and TNO stereotests was measured at 40 cm. viewing distance with a relieving prism, which was calculated according to Sheard's Criterion and the SPC with TNO at 80 cm. The mean stereoacuity measured with Titmus was 40, ±0 SOA with each prism. The mean stereoacuity measured with TNO was more compromised with prism calculated compared to SPC, while TNO was at 80 cm. 42.5, ±38.44 SOA and even more strongly compromised with Sheard's Criterion (70, ±84.14 SOA). However, there was no statistically significant difference (Figure 22). A Repeated

Measures ANOVA test was used to compare the means of stereoacuity. Friedman test showed no statistically significant difference (N=6, Chi-Square=5.706, df=3, p=0.127). It means there is a justification to conduct research to assess the use of TNO at 80 cm. in future work.

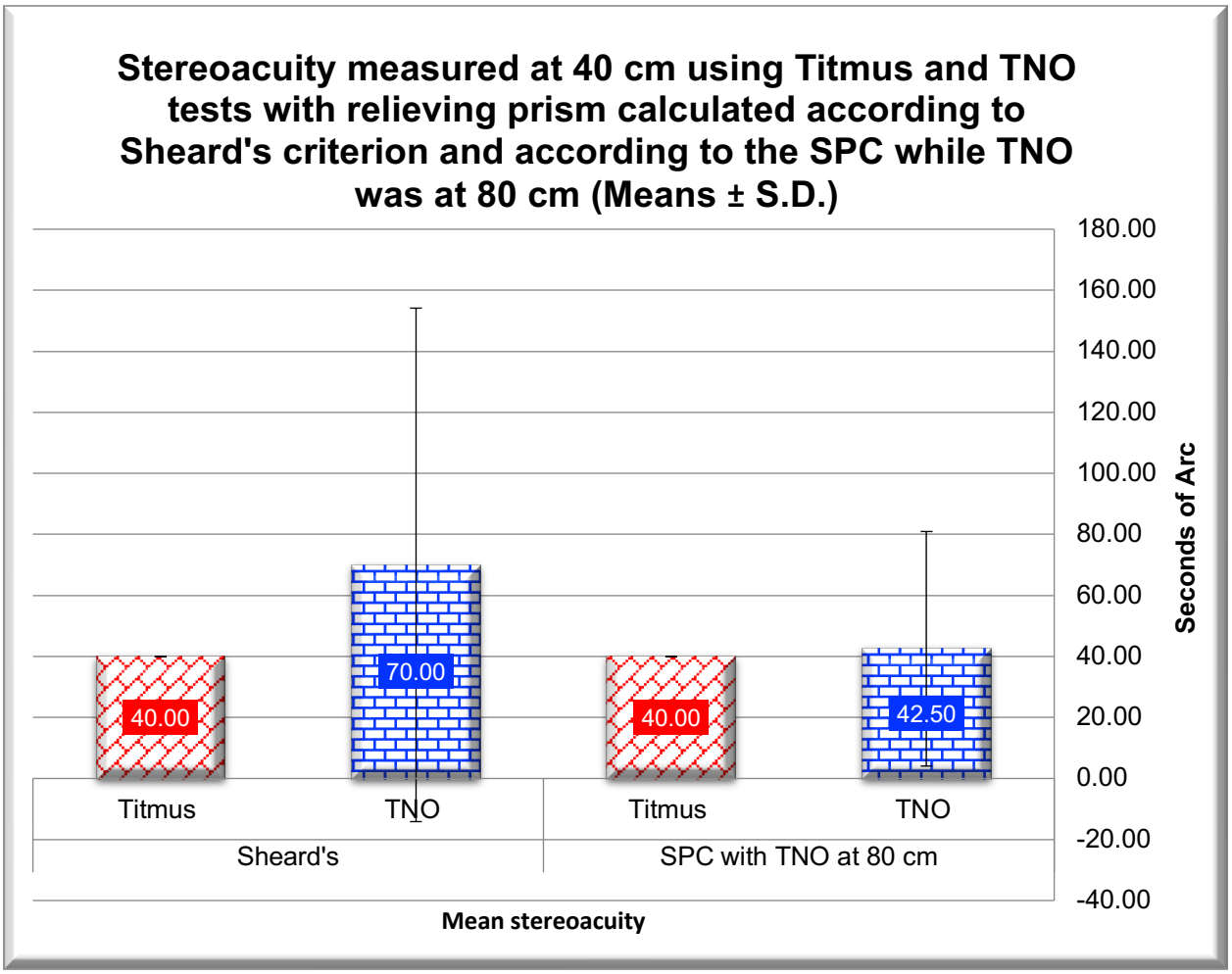


Figure 22: *The graph shows that SPC contributed to a better stereoacuity with TNO stereoacuity (42.5, ±38.44) than Sheard's Criterion (70, ±84.14) and to much lower SD. However, the difference was not significant (p>0.05). The error bars represent the Standard Deviation of the mean.*

6.4. Discussion

The inclusion criterion for this research was a decompensating exophoria at near. Stereoacuity lower than 40 SOA was one of the criteria (Table 3). However, some participants met all the inclusion criteria except for the stereoacuity. These participants were analysed separately in this experiment. There were six subjects in this group.

Each participant in this group underwent stereoacuity measured using four different stereotests: Frisby, Titmus, Randot and TNO. TNO showed more compromised stereoacuity than the other tests. Although the difference was not statistically significant. No statistically significant difference was found supposedly because the sample size is very limited.

Stereoacuity using Titmus and TNO was measured at eighty centimetres viewing distance to reduce the projection angle of the stereotests targets and thereby make the test more accurate. This reduced stereo vision from 180, ±161 to 366.67, ±366.97 SOA on the TNO and from 40, ±0 to 146.67, ±58.88 SOA on Titmus. These results confirm that TNO is more affected since, with an increase in the level of stereotest complexity, the global test rest is much more compromised than the local results. However, this difference was not statistically significant. The reason for the absence of statistical difference may be because the sample size was very limited.

This experiment calculated a relieving prism according to the SPC (with TNO at 80 cm), which amounted to 11, ±3,74 PD, and Sheard's Criterion contributed to 7.22, ±2.65 PD. The SPC contributed to an improvement of TNO stereoacuity. The SPC contributed to the increase in global stereoacuity to a greater extent than the Sheard Criterion. This, once again, indicates the greater effectiveness of the SPC than Sheard's.

6.5. Conclusion

This experiment demonstrated that even though the participants achieved a stereoacuity of 40 SOA on one of a local stereotest, their binocular vision was compromised and can be improved with relieving prism. TNO was shown to be more compromised, suggesting that the TNO may be better at detecting heterophoria decompensation than the other stereotests suggesting it may be more sensitive to heterophoria decompensation. The participants did not meet the inclusion criterion (Chapter 3) for the main experiment (Chapter 4). A relieving prism was not prescribed because global stereoacuity could not be measured accurately enough by applying the standard method.

Extending the stereotests range demonstrated that subjects with 40 SOA on one of the tests actually have compromised binocular vision. Evidence of compromised binocular vision makes it possible to prescribe a prism for subjects in this group. If the range of the TNO is extended, then SPC can be calculated. SPC prism improved the stereoacuity. Validation of the effect of prism prescription was not done in this group because the sample size was limited (6 participants) and because of the time limitation. This amount of prism should be validated in future work to confirm that the level of symptoms will decrease. The results of this experiment suggest that the participants will have a symptom reduction with the SPC prism because the stereoacuity was higher with the relieving prism.

The SPC prism had a stronger effect on increasing stereoacuity than Sheard's Criterion. This suggests that prismatic correction will be appropriate in this group of participants, and the SPC is beneficial. This experiment demonstrated a reduced global stereoacuity in a limited group of participants. This reduction should be tested in a main group of subjects to confirm TNO's greater ability in further work.

7. Vision Therapy

7.1. Introduction

VT is one of the decompensating exophoria at near treatment options. In the author's current practice, the first step is to prescribe a prism to compensate for diplopia to ensure the patient can function normally. Secondly, visual therapy is offered on an in-office basis with home reinforcement.

Since VT is time-consuming and entails a financial burden, not all patients agree to it. Moreover, patients often come to the clinic from other cities, which is an obstacle to undergoing VT. If a subject had not undergone VT, he had only received treatment through prismatic correction. In VT cases, the relieving prism was gradually reduced or completely cancelled with positive dynamics. The participants in this experiment were recruited from "The Relieving Prism Prescribing, According to Sheard's versus the SPC" experiment (Chapter 4) and were using a prismatic correction prescribed according to SPC.

7.2. Methodology

A full optometric examination was carried out (see Chapter 3) at the baseline. The participants were recruited from Sheard's experiment described in Chapter 4. They were self-selected based on proximity and convenience to get to VT sessions. There were no participants from the second cohort, the FD experiment (Chapter 5), because the experiment was conducted later on, and there was a time limitation. If participants from the second cohort had taken part in the experiment, they also would have started VT with the SPC prism since it provided greater symptom relief compared to the FD prism. Thus, at the beginning of the VT, the first and second cohorts would have started from the same point. Because of that, there is no reason to suspect that the second cohort would have behaved any differently from the first cohort. Both cohorts would have been a decompensated exophoria at near prescribed prism using the SPC.

After the participants completed both sessions of prismatic correction in Sheard's experiment (Chapter 4), they were given glasses with a prism prescribed according to the SPC, which provided greater symptom relief than Shard's Criterion prism. The VT

started within one week after the participant finished the two prismatic correction sessions as part of the Sheard's experiment.

The duration of the treatment was 24 sessions, twice a week. Each treatment session lasted for 40-45 minutes, and a home-based treatment session lasted 20 minutes 3 times daily (60 minutes overall). A trained visual therapist administered in-office therapy individually. The VT programme was planned for three sessions ahead. At the end of each treatment session, the dynamics of each exercise were written down. The next three VT treatment sessions programme was planned based on the dynamics. The clinical performance dynamics had been assessed in the middle of therapy, after the 12th treatment session, and at the end, after the 24th treatment session.

The Initial, Follow-Up and Outcome Examinations:

- CT
- NPC
- FR
- FD
- Global and Local stereoacuity using Randot, Titmus and TNO.
- AC/A ration
- Vergence Facility
- NRA/PRA

The in-office treatment is carried out using:

- Anaglyphs and Tranaglyphs;
- Vectograms;
- Prismatic and accommodative flippers;
- Bernell'o Scope;wi
- Aperture Rule;
- Cheiroscope;
- Mirror Stereoscope;
- Rotator;
- Marsden ball.

The in-home treatment is carried out using:

- Brock string;
- Red/Green eccentric circles;
- Barrel card;
- Life- Saver card;
- Pencil Push-up;
- Physiological diplopia with mirror;
- Accommodation jump.

For more detailed information regarding the procedures and how they were delivered, see Appendix 3.

7.3. Results

Shapiro-Wilk demonstrated that most of the data in this chapter was not normally distributed (Table 25).

Table 25: Shapiro-Wilk results for data presented in Chapter 7

The test	Statistic	df	p	Outcome
CT before the VT	0.950	35	0.110	The data are normally distributed
CT after the VT	0.920	35	0.14	The data are not normally distributed
FD before the VT	0.552	53	<0.001	The data are not normally distributed
FD after the VT	0.708	35	<0.001	The data are not normally distributed
Titmus Stereoacuity before the VT	0.650	35	<0.001	The data are not normally distributed
Titmus Stereoacuity after the VT	0.507	53	<0.001	The data are not normally distributed
Randot Stereoacuity	0.764	35	<0.001	The data are not normally distributed

before the VT				
Randot Stereoacuity after the VT	0.845	35	<0.001	The data are not normally distributed
TNO Stereoacuity before the VT	0.795	53	<0.001	The data are not normally distributed
TNO Stereoacuity after the VT	0.781	35	<0.001	The data are not normally distributed
FR Blur point before the VT	0.930	35	0.028	The data are not normally distributed
FR Blur point after the VT	0.937	53	0.091	The data are normally distributed
FR Break point before the VT	0.943	35	0.067	The data are normally distributed
FR Break point after the VT	0.916	35	0.08	The data are normally distributed
FR Recovery point before the VT	0.911	53	0.08	The data are normally distributed
FR Recovery point after the VT	0.921	35	0.015	The data are normally distributed
NPC before the VT	0.860	35	<0.001	The data are not normally distributed
NPC after the VT	0.911	53	0.08	The data are normally distributed

Table 25: *Demonstrates the Chapter 7 normality.*

7.3.1. The participants

Thirty-five participants were recruited for this experiment from the previous Sheard's Criterion experiment (Chapter 4). All the participants had the experience of

wearing Sheard's and SPC prismatic correction. They were provided by SPC prismatic correction before they entered the VT.

The mean age of the participants was 30. Of the 35 subjects, 16 (62 %) were females, and 19 (38 %) were males. All thirty-five subjects underwent all the examinations and VT. The prism was reduced in eleven cases, and in twenty-four cases, it was cancelled after VT treatment. The mean number of in-office VT sessions was 24.

7.3.2. Improvement of the CT

The CT mean measured before the VT was significantly higher (14.49, ±4.34 PD) compared to that after VT (4.8, ±3.18 PD) (Figure 23). The Related Samples Wilcoxon Signed Ranks test showed N=35, Statistic=0, p=<0.001.

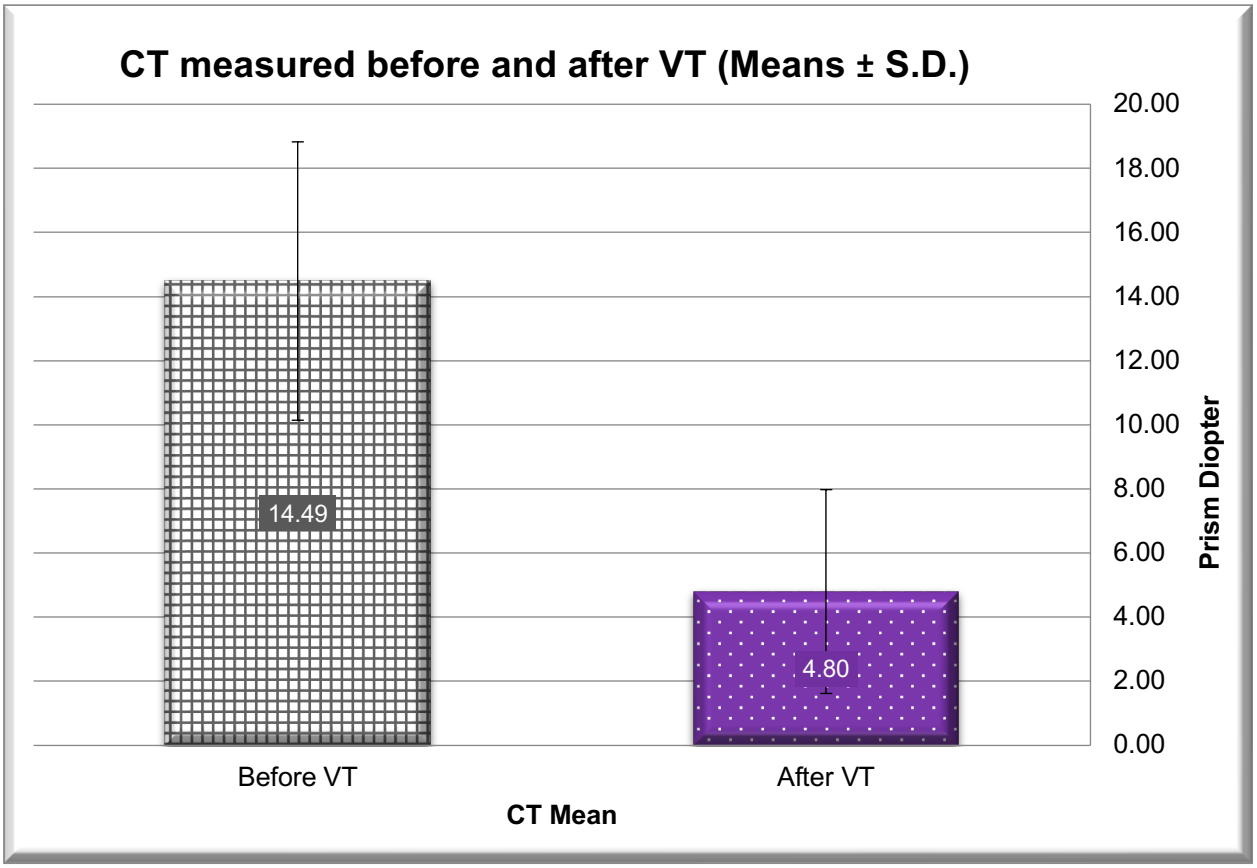


Figure 23: *The graph shows a significant reduction of heterophoria angle from 14.49, ±4.34 before VT to 4.80, ±3.18 PD. after the VT treatment (p<0.05). The error bars represent the Standard Deviation of the mean.*

7.3.3. Improvement of the FD

The FD mean measured before the VT was significantly more compromised (9.63, ±3.24 PD) than that after VT (1.96, ±1.79 PD) (Figure 24). The Related Samples Wilcoxon Signed Ranks test showed N=35, Statistic=120.500, p=0.012.

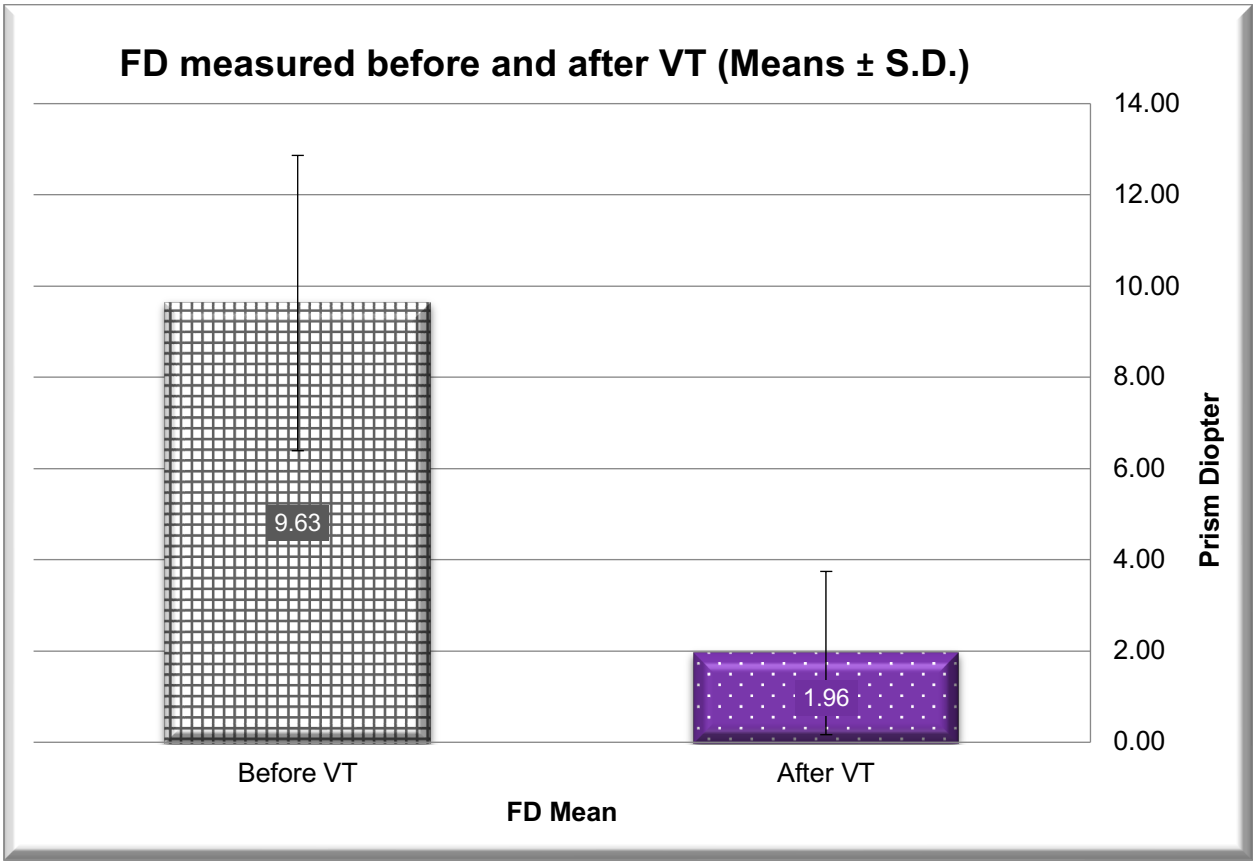


Figure 24: *The graph shows a significant improvement of FD from 9.63, ±3.24 before the VT to 1.96, ±1.79 PD. after the VT treatment ($p<0.05$). The error bars represent the Standard Deviation of the mean.*

7.3.4. Improvement of the Stereoacuity

Table 26 and Figure 25 represent the stereo acuity, which means significant improvement after VT with Titmus, Randot, and TNO.

Table 26: Stereoacuity mean ± S.D. measured with TNO and Titmus stereotests before and after VT				
The stereotest	Before VT		After VT	
	Mean	SD	Mean	SD
Titmus	215.14	201.40	43.14*	6.76
Randot	245.31	184.99	32.87*	18.95
TNO	391.43	213.61	57.86*	39.88

Table 26: *Stereoacuity mean ± S.D. measured with TNO, Titmus and Randot stereotests significantly improved with VT with p<0.05 for each stereotest. * means that there was a statistically significant difference.*

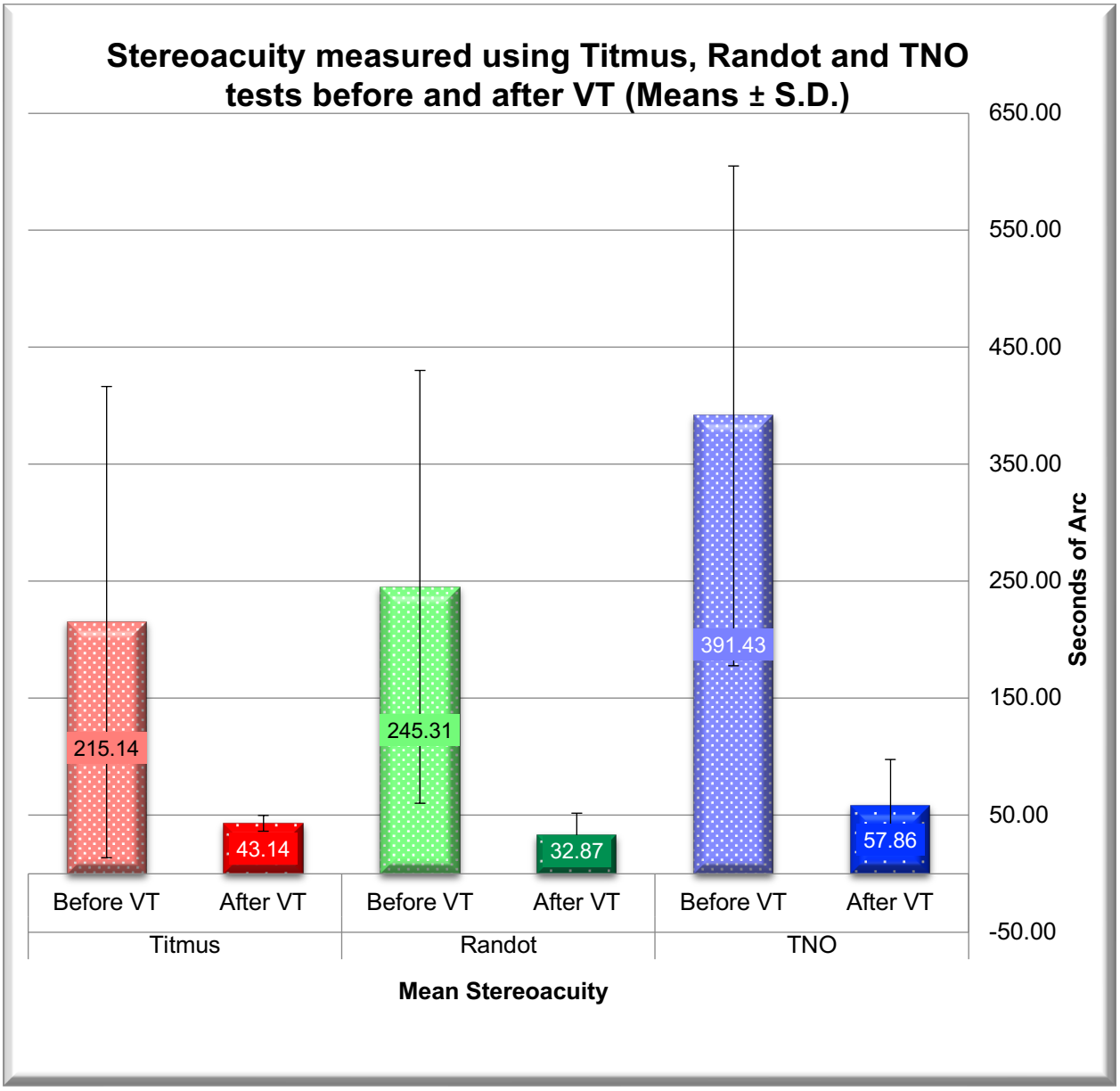


Figure 25: *The graph shows that after VT, stereoacuity was significantly higher*

with all the stereotest ($p<0.05$) than before the treatment. After the treatment, stereoacuity was comparable with each stereotest ($p>0.05$). The error bars represent the Standard Deviation of the mean.

As shown in Figure 38, VT contributed to stereoacuity improvement in all the stereotests. A comparison between the stereoacuity means was performed using the Related Samples Wilcoxon Signed Ranks test, which showed that:

- Titmus stereoacuity significantly improved after VT (N=35, $p<0.001$);
- Randot stereoacuity significantly improved after VT (N=35, $p<0.001$);
- TNO stereoacuity significantly improved after VT (N=35, $p<0.001$).

7.3.5. Improvement of the FR

The FR means measured at Blur, Break and Recovery points before and after VT are represented in Figure 26. VT contributed to a higher FR. A comparison between each FR point means was performed using the Related Samples Wilcoxon Signed Ranks test. The Blur point significantly improved from 10.17 ±5.22 to 15.26 ±5.39 (N-35, Statistic=413.00, p=0.001). The Break point significantly improved from 10.17 ±5.22 to 15.26 ±5.39 (N-35, Statistic=492.00, $p<0.001$). The Recovery point significantly improved from 10.17 ±5.22 to 15.26 ±5.39 (N-35, Statistic=491.00, $p<0.001$).

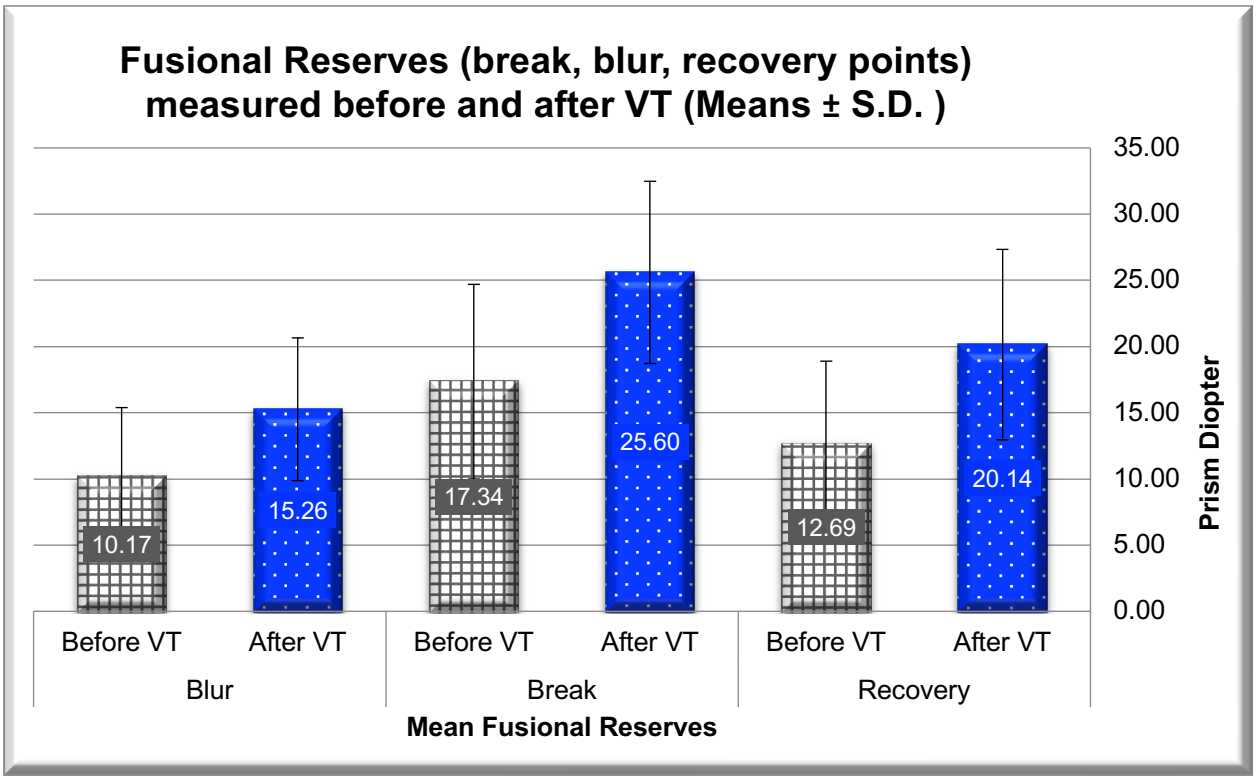


Figure 26: *The graph shows a significant improvement of the FR the Blur point from 10.17, ±5.22 PD to 15.26, ±5.39 PD ($p<0.05$), the Break point from 17.34, ±7.35 PD to 25.60, ±6.88 PD ($p<0.05$), and the Recovery point from 12.69, ±6.21 PD to 20.14, ±7.20 PD ($p<0.05$) after the VT treatment. The error bars represent the Standard Deviation of the mean.*

7.3.6. Improvement of the NPC

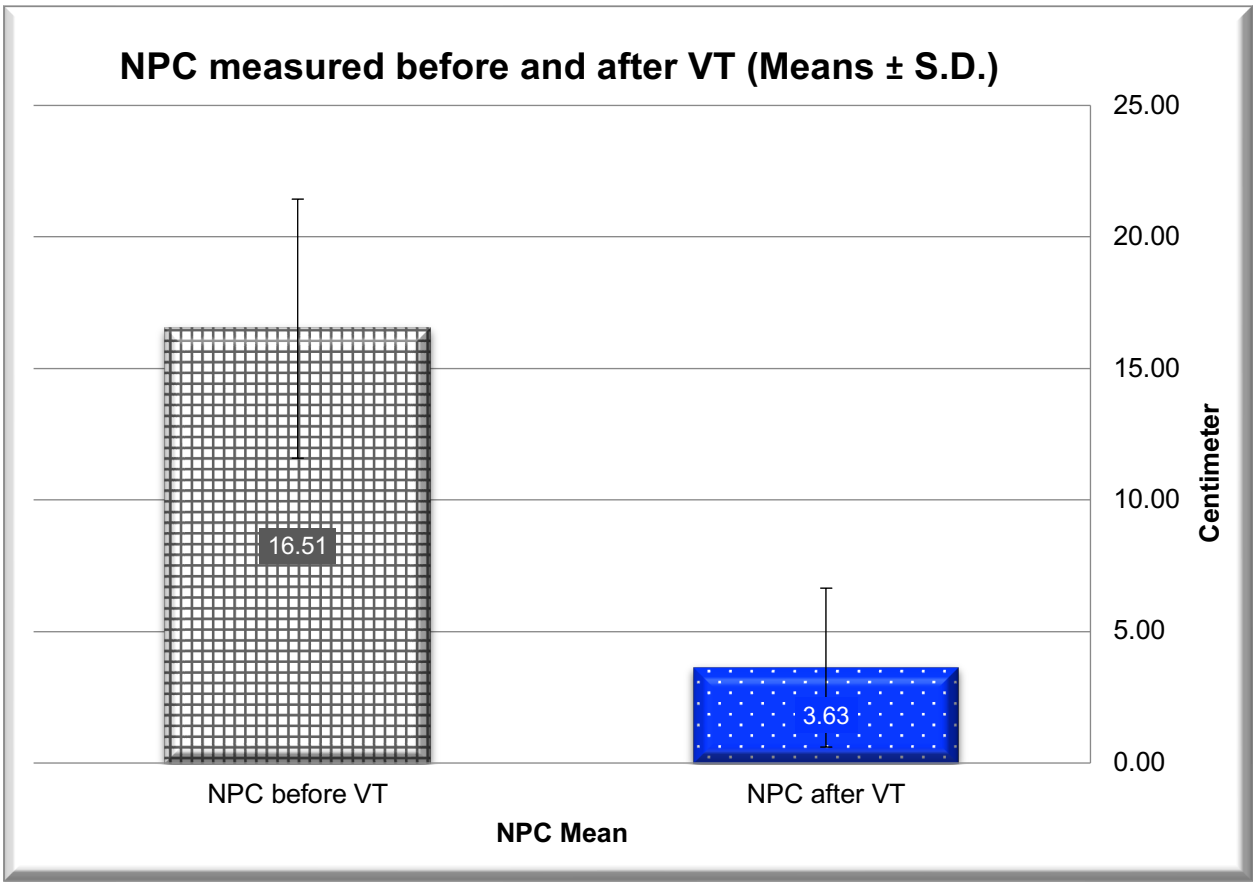


Figure 27: *The graph shows the NPC significant improvement from 16.51, ±4.93 cm. before VT to 3.63, ±3.02 cm. after the VT (p<0.05). The error bars represent the Standard Deviation of the mean.*

The NPC mean significantly improved after VT from 16.51 cm. with a standard deviation of 4.93 centimetres to 3.63 cm. with a standard deviation of 3.02 cm. (Figure 27). The Related Samples Wilcoxon Signed Ranks test showed a statistically significant difference with a very low p<0.001 (N-35).

7.3.7. Improvement of the Modifies CISS

VT contributed to a significant symptom relief from 42.57 with a standard deviation of 6.4 before the treatment to 22.51 with a standard deviation of 4.39 after (Figure 28). The Paired-Sample T-test showed a statistically significant difference with a very low p-value (p<0.001). The value of the T-test statistics was with a degree of freedom 34 and t=31.008.

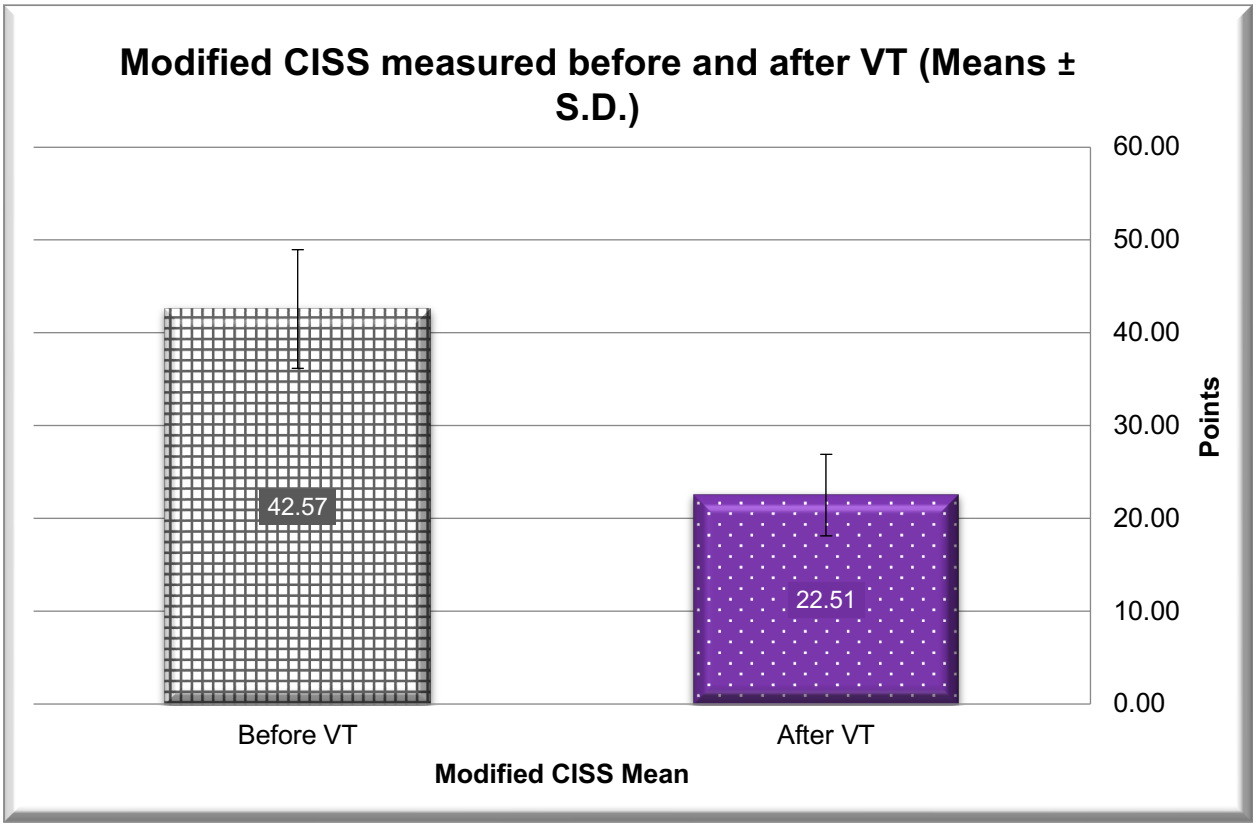


Figure 28: *The graph shows a significant reduction of the symptoms from 42.57, ±6.4 before VT to 22.51, ±4.39 after the VT treatment (p<0.05). The error bars represent the Standard Deviation of the mean.*

Despite the fact that the level of symptoms after VT (22.51, ±4.39) was higher than the normal value (18.83, ±89) obtained with the Normal Group (Chapter 2), there was no statistical difference between them (Figure 29). The Paired-Sample T-test showed no statistically significant difference with a p-value (p=0.568). The value of the T-test statistics was with a degree of freedom 57 and t=-3.309.

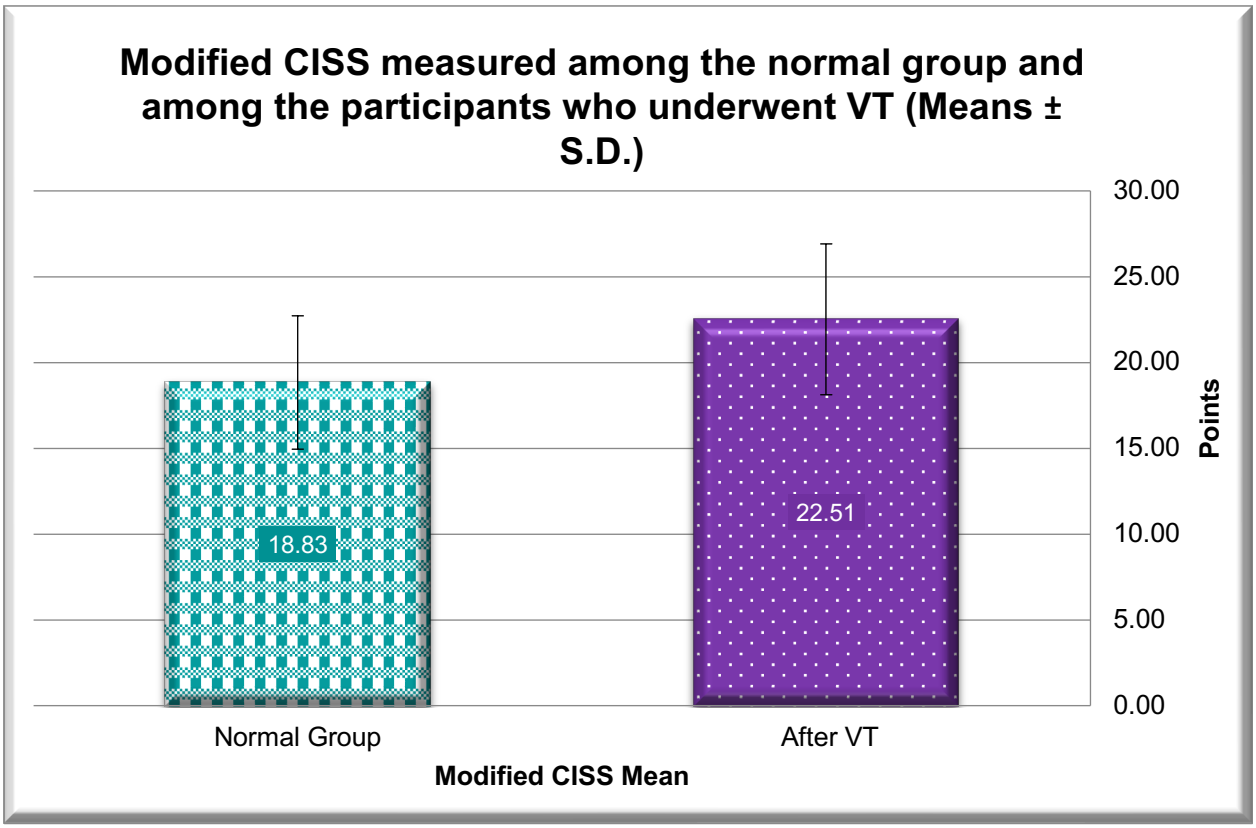


Figure 29: *The graph shows that the level of symptoms in the Normal Group (modified CISS 18.83, ±3.89) and participants who underwent VT (modified CISS 22.51, ±4.39) was comparable (p>0.05). The error bars represent the Standard Deviation of the mean.*

The weakness of this experiment is the absence of a placebo group. It will be beneficial to conduct a study in the future with a placebo prism as a starting point, evaluate the rate of improvement of the clinical signs and symptoms, and compare those to the placebo group data.

7.4. Discussion

VT contributed to a significant reduction in symptoms and improved binocular vision functions. It must be mentioned that VT continued until the functions of the binocular visual system reached normal levels.

In this research, the participants were all symptomatic adults who needed to work with PC, read, learn, etc. Because of that, the greatest reduction in symptoms was preferred for these patients, which was a limitation of this study.

In cases where the positive progression was absent for 12 VT sessions, and the phoria was not fully compensated, a subject remained with a relieving prism. This prism was lower than the prism the subject began the VT with. VT contributed to significant symptom relief; the CISS reduced from 42.57, ±6.40 to 22.51, ±4.39 ($p < 0.001$). Moreover, the modified CISS questionnaire means that after VT, the normal value was established among participants with normal binocular vision, as described in Chapter 2. Aletaha et al. (2018) demonstrated a 100% ($P = 0.003$) decrease in the CISS scores in their study. This means that in-office VT with home reinforcement can be considered a decompensating exophoria treatment method.

The deviation mean angle significantly decreased from 14.49, ±4.34 PD to 4.8, ±3.18 PD ($p < 0.001$) as a VT result. Aletaha et al. (2018) demonstrated a decrease of 85% in NPC ($P = 0.2$) due to office-based VT. PFR significantly increased as a result of VT. The blur point mean increased from 10.17, ±5.22 PD to 15.26, ±5.39 PD ($p < 0.001$); the break point increased from 17.34, ±7.35 PD to 25.6, ±6.88 PD ($p < 0.001$). The recovery point increased from 12.69, ±6.12 PD to 20.14, ±7.2 PD ($p < 0.001$). Scheiman et al. (2005) demonstrated that after 12 weeks of office-based vision therapy, PFR significantly increased from 11.3 PD to 29.7 PD ($p=0.001$). Westman and Liinamaa (2012) demonstrated the improvement of FR in their study. The mean change in FR measured with the major amblyoscope was 18.6 PD (SD 12.2) degrees after the VT. PFV increased by 100% ($P < 0.001$) in the Aletaha et al. (2018) study, and Scheiman et al. (2010) demonstrated PFR improvement after 12 weeks of VT as well as Jang et al., 2017 after 8 weeks of VT. VT improved NPC from 16.51, ±4.93 cm. to 3.63, ±.02 cm ($p < 0.001$). Scheiman et al. (2005) demonstrated a significant improvement in NPC (12.8 cm to 5.3 cm, $p=0.002$) in their research after 12 weeks of office-based VT. NPC improved by 96% ($P = 0.4$) in the study of Aletaha et al. (2018). Scheiman et al., 2010 demonstrated NPC improvement after 12 weeks of VT. After eight weeks of vision therapy, the average NPC improved by approximately 5.48б ± 0.96 cm in all participants in the Jang et al. (2017) study. The question in this study was: will the VT be beneficial with SPC relieving prism, which provided a higher value than Sheard's and FD, or not? The outcome of the study was that VT brought to a better performance of the participant's binocular vision with a starting point with SPC prism. A randomised control trial is needed to compare the efficacy of the starting point on the VT.

VT brought to FD mean improvement from 9.63, ±.24 PD to 1.96, ±79 PD ($p < 0.001$). Mean stereoacuity improved as well as a result of VT. Titmus improved from 215.14, ±84.99 SOA to 43.14, ± 6.76 ($p < 0.001$); Randot improved from 245.31, ±184.99 SOA to 32.87, ±18.95 SOA ($p < 0.001$); TNO improved from 391.43, ±213.61 SOA to 57.86, ±39.88 SOA ($p < 0.001$). After the VT, the stereoacuity measured by all three tests did not differ statistically significantly.

Working with a PC or drive or doing any everyday tasks with diplopia is almost impossible. Because of that, a relieving prism is prescribed first to relieve the symptoms. VT is recommended to prevent a progression of heterophoria and reduce or eliminate the prismatic component of the optical correction.

A relieving prism should be prescribed for patients with exophoria who suffer from symptoms to allow them to function well. However, the prism value that should be prescribed is a dilemma. A higher prism may suggest that it might take longer for patients to get out of the prism. On the other hand, greater symptom relief and more stable binocularity by maximising the stereoacuity would presumably make the subject more responsive to VT. The prism prescribing may be a temporary measure, but using the SPC and maximising the stereoacuity theoretically, should make the subject maximally sensitive to VT because the prism would presumably provide the best starting point. The prism prescribed according to the SPC has resulted in virtually being successful in VT in all participants. The VT outcome was very successful, with a starting point of prism maximising the stereoacuity. Therefore, maximising the stereo status of the subjects potentially brings a high VT success rate. The experiment demonstrated that the SPC allow for prism reduction using VT. It means that the starting point with SPC prims was effective. However, Sheard's Criterion and FD prism were not assessed as starting points and were not compared to the SPC prism. A randomised controlled experiment to compare the starting point with three different relieving prism amounts prescribed according to Sheard's Criterion, FD method, and SPC was not carried out because of a time limitation caused by COVID-19 restrictions. Further work needs to be done to refine the starting prism value to reduce the timeframe needed to reduce the prism (see 9.4 for further discussion).

7.5. Conclusion

The participants were prescribed SPC prismatic correction before entering the VT, resulting in them being virtually symptom-free. The VT outcome was very positive; the prism was reduced in eleven cases, and in twenty-four cases, it was cancelled completely. By reducing the prism, the subjects are less dependent on the prismatic correction; they may not have to wear glasses all the time.

In 31.42% of the cases, the prism was reduced from that given before VT, and in 68.58% of cases, the prism was cancelled after VT treatment. VT significantly relieved symptoms and improved the functions of the binocular system, such as local and global stereopsis, deviation angle, FD, FR, and NPC.

It should be noted that factors such as lack of motivation, time or material obstacles, etc., may impact the prognosis of VT. This study had more sessions than many researchers reported previously. Adler (2002) reported that in his study, there was a need to continue the VT up to 20 in-office sessions. The participants underwent sessions in this study.

VT can be recommended as an effective treatment for decompensating exophoria. However, the patient must be informed about the expected duration of the treatment, the need to complete homework, and the features of the treatment itself.

Participants having symptoms have to be compensated with a relieving prism. A prism that provides higher stereoacuity results in higher symptom relief. A relieving prism can be prescribed for a short-term or a long-term option. Subjects who refused VT, who were not suitable for VT or for whom VT was not fully successful were prescribed a relieving prism for the long term. A short-term prism was applied to participants about to enrol in VT.

8. Further Work

This work was the first approach to establishing a relieving prism prescribing method based on stereoacuity. The SPC was developed and compared to the methods currently used in optometry practice, Sheard's Criterion, and the FD method. There is room for improvement in the methodology of SPC, Sheard's Criterion and the FD.

8.1. Improvement of Sheard's Criterion

Sheard's Criterion was calculated taking into account the FR blur point. However, patients report that before blurring occurs, they feel slight discomfort, heaviness in the eyes, pain, tension, etc., while FR was measured. For the purpose of this thesis, the amount of prism that contributes to this feeling will be called the "Something" point. The Something point was measured and compared with Blur, Break, and Recovery points (Figure 30).

A comparison between the FR point means was performed using the Repeated Measures ANOVA test. ANOVA showed a statistically significant difference with a very low p-value ($p<0.001$). The value of the test statistics is $F=53.573$ with a degree of freedom 3. A Tukey post-hoc test was performed to determine the difference between each test. The tests showed a statistically significant difference between each point ($p<0.001$) except of between Break and recovery points ($p>0.05$). It means that the Something point occurs with a significantly lower prism than the Blur point while FR is being measured.

Shapiro-Wilk demonstrated that the data were not normally distributed (Table 27).

Table 27: Shapiro-Wilk results for Fusional Reserves four points ("Something", Blur, Break, Recovery)				
Stereotest and measurement condition	Statistic	df	p	Outcome
Something point	0.940	69	0.002	The data are not normally distributed
Blur point	0.938	69	0.002	The data are not normally distributed
Break piont	0.916	69	0.028	The data are not normally distributed
Recovery point	0.6942	69	0.003	The data are not normally distributed

Table 17: *Demonstrates the FR measurement Something, Blur, Break and Recovery points provided non-normalized data using the Shapiro-Wilk test.*

Since the data were not normally distributed, nonparametric tests were performed. Friedman test showed a statistically significant difference (N=69, Chi-square=183.816, df=3, p<0.001) between the FR points mean, and the Wilcoxon Signed Rank test showed a significant difference between each mean (Table 28).

Table 28: Fusional Reserves four points ("Something", Blur, Break, Recovery) mean comparison using Wilcoxon Signed Rank test				
Stereotest and measurement condition	Stereotest and measurement condition	z	p	Outcome
Something	Blur	-6.904	<0.001	Statistically significant
Something	Break	-7.226	<0.001	Statistically significant
Something	Recovery	-7.003	<0.001	Statistically significant
Blur	Break	-7.112	<0.001	Statistically significant
Blur	Recovery	-4.495	<0.001	Statistically significant
Break	Recovery	-7.061	<0.001	Statistically significant

Table 28: *The FR points mean was statistically significantly different (p=<0.001).*

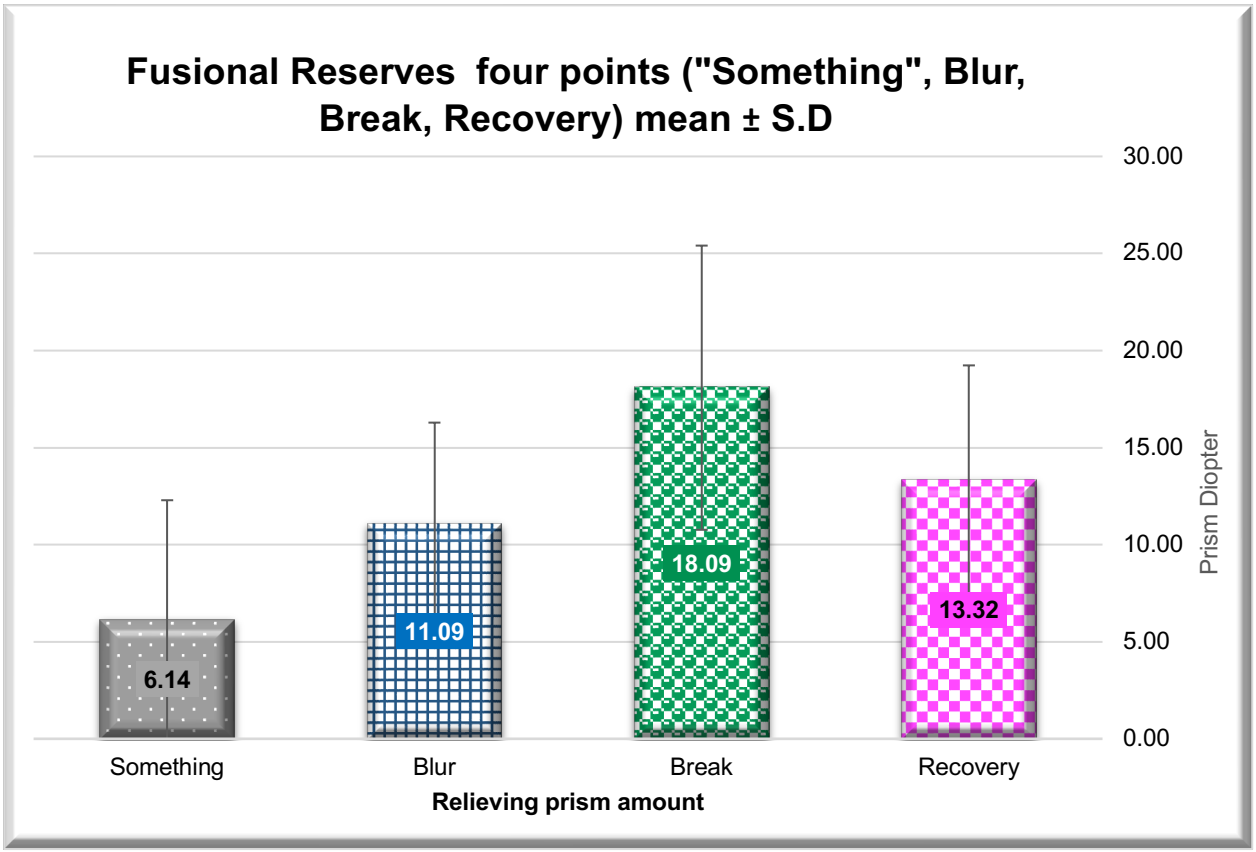


Figure 30: *The graph shows that the Something point (6.14, ±3.33 PD) came before the Break point (11.09, ±5.20), and the difference was significant (p<0.05). The error bars represent the Standard Deviation of the mean.*

The reliving prism using the Something point and the Blur point was calculated according to Sheard's Criterion (Figure 31). The Paired-Sample T-test showed a statistically significant difference with a very low p-value (p<0.001). The value of the T-test statistics was with a degree of freedom 68 and t=15.590.

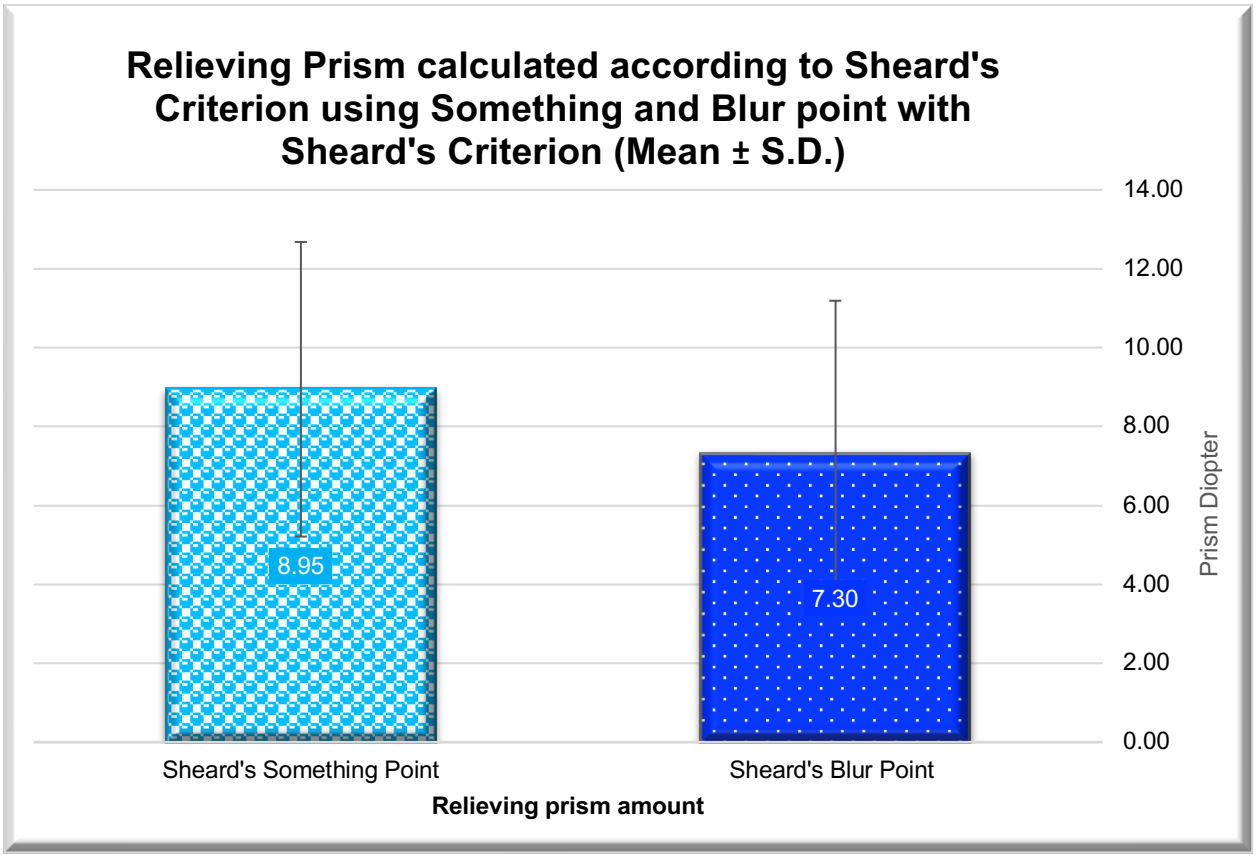


Figure 31: *The graph shows that the relieving prism calculated according to the Something point was significantly higher than the Blur point ($p<0.05$). The error bars represent the Standard Deviation of the mean.*

Since the Something point provided a higher relieving prism than the Blur point, future work needs to assess the symptom relief using the Something point in Sheard's Criterion instead of the Blur point and compare it to the SPC value of the relieving prism.

8.2. Improvement of the FD Method

Improving FD is complicated because multiplying the results by any factor that brings the relieving prism to a value provided by SPC would not work on participants with FD equal to zero. Manipulation with zero will give nothing but zero. Therefore, FD is limited to be improved.

8.3. Improvement of SPC

SPC has been shown to be effective in relieving symptoms. However, the author

recognise that the criterion can be improved in several ways. First, the step size for SPC was chosen for this study according to the prism bar. A smaller step size might provide a more accurate relieving prism amount. This may be particularly true with a higher degree of heterophoria since they are not getting a high stereoacuity with relieving prism. Maximising the stereoacuity using SPC suggests that the stereo should presumably get to 40 SOA. The fact that subjects with higher heterophoria did not achieve this may suggest that they have a fundamentally compromised stereo mechanism, which limits the capacity of getting a high stereoacuity.

Second, the effectiveness of SPC should be tested on the paediatric population, on patients with exophoria at a distance, and on esophoria at a distance and near. Other aspects are discussed below.

8.3.1. Other Stereotests for SPC

TNO stereoacuity was chosen to be a basis for SPC since it is a commonly used global stereotests in the optometry practice (Zhao & Wu, 2019). However, Randot is also quite widely used (Zhao & Wu, 2019), which gives fewer monocular cues than the Titmus test (Lee & McIntyre, 1996). Stereoacuity gained with Frisby, Titmus, Randot and TNO was used to calculate the SPC.

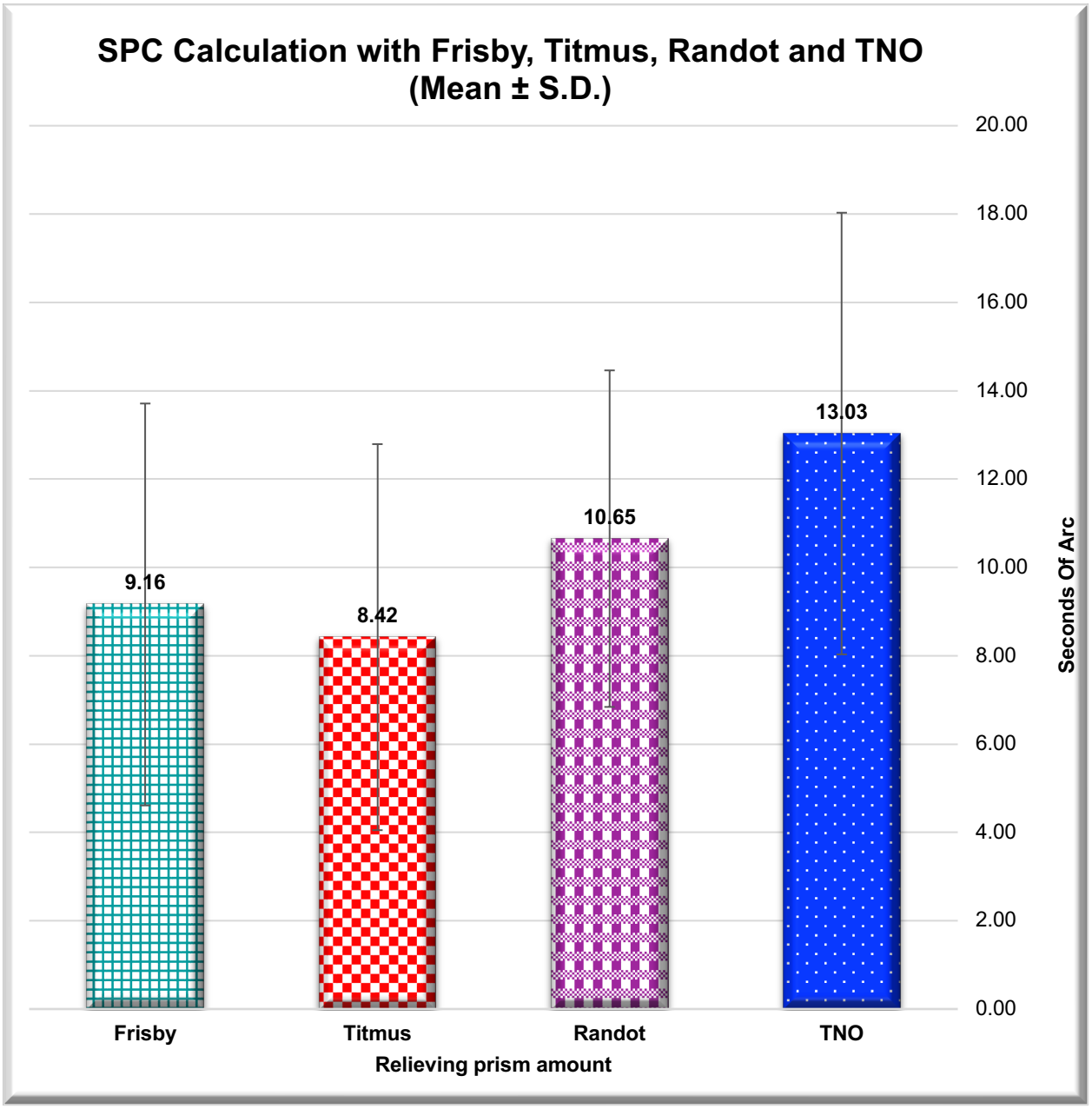


Figure 32: *The graph shows that the relieving prism calculated according to Randot (10.65, ±3.81) was significantly higher than with Frisby (9.16, ±4.55) and with Titmus (8.42, ± 4.37) p<0.05 and was lower than with TNO (13.03, ±5) p=0.05. The error bars represent the Standard Deviation of the mean.*

Figure 32 demonstrates that Randot (10.65, ±3.81) provided a significantly higher relieving prism than Titmus (8.42, ± 4.37) and Frisby (9.16, ±4.55), but lower than TNO (13.03, ±5). There was no statistically significant difference between TNO and Randot. Repeated Measures ANOVA test showed a statistically significant difference ($p<0.001$, $F= 12.578$, $Df=3$), and the post-hoc Tukey test showed a significant difference between TNO and Frisby ($p<0.05$), TNO and Titmus ($p<0.05$). There was no significant

difference between Frisby and Titmus ($p>0.05$) and Frisby and Randot ($p>0.05$). The p-value between TNO and Randot Titmus and Randot was 0.05.

The conclusion drawn from the previous was that Randot may be an alternative to TNO in the SPC. Although TNO is expected to provide a higher rate of symptom reduction because it provides a higher relieving prism, Randot could be examined as an alternative to TNO in future work.

8.3.2. Correlation between relieving prisms and symptom levels

A correlation (Appendix 5) between relieving prisms and symptom levels was not found in this work. However, there was a stronger positive trend with the SPC than with Sheard's Criterion and the FD method. It has already been demonstrated that a higher prism provides a higher relief from symptoms. A Modified Sheard's Criterion and FD method were calculated. A Modified Sheard's Criterion was correlated to CISS gained after the period with prismatic correction prescribed according to Sheard's Criterion. A Modified FD method was correlated to CISS gained after the period with prismatic correction prescribed according to the FD method. There was no significant correlation. This means that on an individual basis, either a Modified Sheard's Criterion or Modified FD method will work properly. Future work is needed to do an extra measurement in order to develop a more refined method of prism calculation. Reanalysing the data in the way described in Appendix 5 showed no correlation. However, it should be stated that the data were manipulated, which suggests that further work should be done.

8.3.3. More accurate TNO

It has already been said that a more sensitive TNO stereotest might provide a more accurate prism value. A smaller step size will make the tests more accurate. It is assumed that the TNO stereotest, which will be carried out using a tablet, will be able to provide this greater accuracy by reducing the step size of the targets. This could make the TNO test more appropriate. The colours of the test should match the filters, and the calibration will be needed. The tablet should also be programmed not to be adjustable to light, so colours and screen brightness cannot be changed. This idea can be developed in future work.

8.3.4. TNO at 80 cm

As demonstrated in Chapter 6, TNO becomes more effective when a measurement is conducted at an 80 cm viewing distance. A group of patients with decompensating exophoria whose stereoacuity reaches 40 SOA on one of the stereotests may experience a reduction in symptoms with relieving prism. TNO stereoacuity improved with a prism, indicating that prismatic correction would be appropriate in this group of participants. It makes sense to conduct such research to assess SPC with TNO at 80 cm. among this group of patients in future work.

8.4. VT

The participants were recruited from Sheard's experiment (Chapter 4) instead of from the general population, so they may not be able to represent a whole population. On the other hand, the participants who participated in the VT experiment were recruited only because of their proximity and convenience to the VT sessions. There is no reason to suggest that people living farther away from the clinic where VT was provided will be massively different from those who live close enough to have the VT. However, the sample was not randomly recruited, which may be a reason for bias.

In this research, the participants were all symptomatic adults who needed to work with PC, read, learn, etc. Because of that, the most significant reduction in symptoms was preferred for these patients, which was a limitation of this study. Because of that, a prismatic correction, according to SPC, was provided to the participants at the VT starting point immediately after they completed Sheard's experiment (Chapter 4).

The main VT outcome was a reduction of the relieving prism amount. SPC provided a higher prism amount than FD and Sheard's Criterion gave. Presumably, since a higher prism provided a higher stereoacuity and thus a more stable binocular vision, the VT might be more effective with a higher prism at the starting point. With more stable binocular vision, a subject is more able to do VT; he is more responsive to VT. Another argument to support the idea that a subject should be prescribed with an SPC prism was that presumably, by the time the prism is lowered to the FD or Sheard's level, the functions of the binocular system (FR, FD, NPC, etc.) would be higher than pre-VT starting point if Sheard's or FD prism would have been prescribed. This means

the subject would have a more stable binocular system at the same rate of relieving prisms if the starting point were SPC.

On the other hand, a lower relieving prism at the starting point may result in a higher rate of prism reduction with VT. An “overprescribed” prism may result in underloading in the VT sessions rather than challenging the binocular system. Moreover, the SPC was aimed to gain the minimum prism amount that provided a maximum global stereoacuity.

However, due to the time limitation of this research, a randomised controlled study to compare the VT effectiveness with three different prism amounts (Sheard’s Criterion, FD method and SPC) at a starting point was not done. Future work should assess the statement that giving a higher prism before VT provides better results (a higher prism reduction rate) than a lower amount of prism. Further work should assess the hypothesis that a higher amount of prism would provide better binocular vision stability, making VT more effective. This should be proven by requiring less time and fewer VT sessions to reach the discharge point.

Future work should assess the VT starting point for exophoria at a distance, esophoria for distance and near and for subjects with vertical deviation.

In this experiment, only one group of participants were included, those who were given a relieving prism calculated according to SPC. In the future, a randomised controlled trial should be performed to compare the outcome of the prism amount starting point. Such a study should include four groups according to the relieving prism with which VT will be started: SPC, Sheard’s Criterion, the FD method and the placebo group (no relieving prism). The outcome of such a study may be the rate of decrease of relieving prism and time taken until discharge. The hypothesis of such research may be that a higher value of prism should give a better heterophoria compensation that will allow VT to be more effective, which should result in a more rapid decrease in the amount of relieving prism, which in turn should lead to a shorter timescale overall to get out of prism and to discharge.

Another option is to fully correct the phoria at the beginning, rather than aiming for any minimal prism, to see if symptoms are improved further and if therapy becomes more efficient.

8.5. Heterophoria

This research was conducted among subjects with decompensating exophoria at near because it is the most common binocular vision disorder (Montés-Micó, 2001; Clark & Clark, 2015; García-Muñoz, Carbonell-Bonete, Cantó-Cerdán & Cacho-Martínez, 2016; Hashemi et al., 2017). SPC was shown to be effective in this group.

However, future work should assess the effectiveness of SPC among participants with exophoria at distance, esophoria at distance and near, and vertical heterophoria. Distance exo and eso phoria cannot be assessed at the moment because there is no distance TNO stereotest. There is a need to develop a distance and a global stereotest to conduct such a study. Moreover, subjects with eso deviation behave differently from subjects with exo deviation; positive and negative fusional reserves have different normal values (Alvarez et al., 2010), and the approach may be reevaluated. Eso phoria at near is less common than exo, and because of that, it may take a longer time period to gather participants for research like that.

Vertical deviation will probably affect stereopsis but in a different way. Stereopsis is a horizontal disparity processing system, whereas vertical phoria will provide a vertical disparity. This means that SPC might be ineffective in a vertical deviation. However, the idea of prescribing a minimum prism for maximum global stereoacuity should be assessed among subjects with vertical phoria in future work.

8.6. Full Phoria Correction

The relieving prism prescribed according to the SPC brought a virtually normal level of symptoms. However, a full phoria correction may give further improvement. A randomised controlled trial comparing SPC with a full phoria correction evaluating the impact on symptoms would be advisable to explore this aspect in further work.

8.7. Conclusion

Additional experiments were not done because of a time limitation, which was partially due to COVID-19. COVID-19 restrictions have resulted in delays in obtaining ethical approval and restrictions in clinical practice.

9. General Discussion

The consensus regarding the prism prescribing method for decompensating exo phoria near the adult population is absent. The primary investigations are the motor (Sheard's Criterion) and the sensory (FD) approaches, which do not consider the stereoacuity. However, stereoacuity plays a significant role in binocular vision assessment and, therefore, should be considered in prism prescribing. The pilot study (Rinsky, 2017) demonstrated that global stereopsis is more vulnerable to heterophoria decompensation. Because of that, the SPC was developed based on global stereopsis.

The SPC relieving prism prescribing Criterion is a minimal prism contributing to the highest global stereoacuity using the TNO test. This approach uses global stereoacuity as a fundamental prism-calculating criterion. The new method gives a higher prism amount than Sheard's and FD method, contributing to greater symptom reduction and a higher local and global stereoacuity. Moreover, the SPC prism prescribing Criterion reduced the symptoms and brought them to a normal value.

VT is another effective treatment for decompensating exophoria at near, which reduces the symptoms and improves binocular system test results. However, the procedure is time-consuming and entails a financial burden. These obstacles do not allow VT to be provided to every patient who needs it.

9.1. Limitations of this Study

In terms of methodology, the present research demonstrated, for the first time (to the best of the author's knowledge), that global stereoacuity was a useful tool for prism prescribing. Such a methodology was a prerequisite for further clinical studies. The findings are the first attempt since the sample size and the follow-up period were limited. Another limitation of this study was that participants under the age of eighteen years old were not included. In addition, this study looked only at exophoria at near. Because of the limitations, further studies are needed.

There is an opportunity in the future to refine the exact methodology. Moreover, a more accurate stereotest presumably will provide a more accurate relieving prism

amount calculation. For this reason, there is a need to develop a more accurate global stereo test with smaller steps that can measure more precise SOA. The regular Snellen chart allows measurements only up to 6/6, while LogMar goes beyond 6/6, making it possible to measure visual acuity more accurately (Kaiser, 2009). A more precise stereotest might give a more precise prism and, therefore, a better methodology. Experiment results with participants with normal stereoacuity but compromised binocular vision (Chapter 6) confirm that more accurate stereotests will probably provide a more accurate stereoacuity threshold. This threshold will allow for a finer prism calculation.

Another limitation was that the participants were given 15 seconds to give an answer on the stereotests. This time period was chosen to avoid Slow Vergence Adaptation. There is no clinically proven justification for this time period. Another limitation was that the relieving prism was measured according to the SPC with step sizes according to the prism bar. Therefore, the prism value may not be absolutely accurate. These limitations can be considered in future work.

Another limitation of this study was the use of a step size according to the prism bar in calculating the relieving prism. Using smaller step sizes in asymptomatic patients could potentially lead to more accurate prism calculations. The 2 PD steps were chosen based on previous studies, and symptomatic participants had relatively high relieving prisms. However, a smaller step size could offer a more precise prism, for example a Risley prism. This could be a focus of future research.

The typical way for TNO measurement is for the subject to provide a correct answer for both figures of the same stereoacuity. The participant passed the test in this research, providing one or two correct answers. In Randot, there are three figures for each stereoacuity, and in Titmus 4. In order to do TNO similar to other stereotests in the context of guessing the right answer, this was made.

The statistics in this thesis were simple. More advanced and more sophisticated statistics were not done because this was a pilot study (Rinsky, 2017), and the authors wanted to get simple yes or no answers to the experiments that were carried out. Additional aspects could be assessed if the methodology is refined in future work and more accurate TNO tests are developed (see Chapter 8) to provide a more accurate

relieving prism value. A comparison between small phorias and big phorias can be made, but the method may differ, as well as method for eso and vertical deviation.

10. General Conclusion

The three main treatment options for decompensated heterophoria are relieving prism, spherical manipulation and VT (Evans, 2002). Decompensating heterophoria contributes to the symptoms that prevent the person from working, learning or doing everyday work. In order to reduce or eliminate the symptoms, decompensating heterophoria should be managed. VT is time-consuming, and the symptom relief due to treatment does not occur immediately. In order to allow the person to function comfortably as quickly as possible and to allow the use of his binocular system, a prism should be prescribed even if the person is going to undergo VT. This prism can be gradually reduced along the positive dynamics and cancelled in cases where this is possible. This study demonstrated that the SPC prism prescribing Criterion is beneficial over Sheard's Criterion and the FD method. Moreover, the SPC is an easy and quick method that does not require many tests. It uses stereo vision, which in turn relies on both the motor and sensory parts of the binocular system. It uses a state-of-the-art diagnostic test (TNO), which is available to optometrists around the world. Despite the fact that this research was the first approach to use TNO as a relieving prism prescribing technique, it can be recommended for practice. Nevertheless, further study is needed. However, a practitioner will decide what criteria to use to prescribe prism.

This research has opened up new possibilities with the TNO global stereoacuity test. Promising results have been shown by using it as a screening tool to measure and calculate relieving prisms for decompensating exophoria at near. The TNO test, known for its sensitivity to decompensating exophoria, has provided a higher relieving prism than the commonly used Sheard's Criterion and the FD method. Importantly, the level of symptoms approached that of normal patients without any statistical difference. This suggests a potential for significant symptom relief in the future.

The TNO stereotest has relatively big steps, which don't allow for accurate global stereoacuity measurements. A smaller step size would enable the practitioner to measure the absolute threshold rather than stop at a level that the test provides. A design of a more accurate TNO in order to have a more accurate clinical measure could provide a more accurate relieving prism calculation than what was done in this research. The justification for the above is the results of an experiment called

"Decompensating Heterophoria with Normal Stereoacuity", where the stereoacuity using Titmus and TNO was measured at 80 centimetres. The experiment demonstrated that TNO is more compromised by heterophoria decompensation than the local stereotest. Its ability can be increased by doubling the testing distance at a distance of 80 centimetres instead of 40 centimetres. The question that arises is whether it will bring to a higher prism and will that higher prism will bring even greater symptom relief. In order to answer this question, a more accurate TNO test with a smaller step size should be manufactured.

Another idea for further work is to recruit asymptomatic participants with decompensating exophoria and compromised stereopsis. The participants will be asked to fill in a modified CISS questionnaire, and a relieving prism, according to the SPC, will be prescribed for six weeks. The hypothesis is that the subjects with decompensating exophoria may not be aware that they are having symptoms. A person with exophoria can be convinced that eye strain and tiredness, particularly at night and at the end of the day, are normal feelings and that people do not read at half past five. A relieving prism could be beneficial in this group of patients. Filling in the modified CISS questionnaire may show a reduction of symptoms and may reveal this aspect. If so, relieving prism may be beneficial to prescribe in cases with no strong symptoms but in cases where prism brings a higher Global stereoacuity.

This work demonstrated that TNO may be used as a prism prescribing method. A practitioner may benefit from this research by having an accurate, quick, and simple screening tool for exophoria and an accurate, quick, and simple relieving prism prescribing technique for near decompensating exophoria among the adult population. Moreover, in cases where decompensating exophoria is diagnosed using the SPC, a practitioner will have evidence that VT is needed, and the patient will be referred.

The results of this research allow the author to recommend the SPC as a simple and fast method for prescribing prisms in an optometry practice. This method was shown to be beneficial over the currently used Sheard's Criterion and FD methods. The SPC method should be used in a standard 40 cm. since it will provide a relieving prism in the vast majority of the decompensating heterophoria cases. Since there was no statistically significant difference between the three repeated measurements of the SPC prism, in the everyday practice it would be enough to accomplish one measurement

with the TNO stereotest rather than three. However, there is room for further improvement of the method (see Chapter 8).

Future work may provide a more precise technique for prescribing relieving prisms in different cases, such as exophoria for far and near and esophoria for far and near. Research among children with decompensating heterophoria is another issue. However, decompensating heterophoria contributes to symptoms that should be managed as soon as possible. The optometrist is responsible and able to decide which criterion will be beneficial to use in prism prescribing.

11. References, Bibliography and Recent Reviews

11.1. References

Abd Manan, F., Jenkins, T. C. & Collinge, A. J. (2001). The Effect of Clinical Visual Stress on Stereoacuity Measured with the TNO Test. *Malaysian Journal of Medical Science*. 8(2):25-31. PMID: 22893757; PMCID: PMC3413646.

Abri Aghdam, K., Zand, A., Soltan Sanjari, M., Khorramdel, S. & Asadi, R. (2021). Overminus Lens Therapy in the Management of Children with Intermittent Exotropia. *Journal of Current Ophthalmology*. 26;33(1):36-40. doi: 10.4103/JOCO.JOCO_17_20. PMID: 34084955; PMCID: PMC8102942.

Adler, P. (2002). Efficacy of treatment for convergence insufficiency using vision therapy. *Ophthalmic and Physiological Optics*. 22(6):565-71. doi: 10.1046/j.1475-1313.2002.00080.x. PMID: 12477022.

Aletaha, M., Daneshvar, F., Mosallaei, M., Bagheri, A. & Khalili, M. R. (2018). Comparison of Three Vision Therapy Approaches for Convergence Insufficiency. *Journal of Ophthalmic and Vision Research*. Sep;13(3):307-314. doi: 10.4103/jovr.jovr_99_17. PMID: 30090188; PMCID: PMC6058546.

Alizadeh, Y., Medghalchi, A., Soltanipour, S., Mohammadi, M. J., Soltani-Moghadam, R., Behboudi, H., … Soleimani, A. (2023). Role of Overcorrecting Minus Lens Therapy in Intermittent Exotropia for Prevention of Constant Exotropia in Children Under the Age of 7 Years. *International Journal of Preventive Medicine*. 22;14:80. doi: 10.4103/ijpvm.ijpvm_130_22. PMID: 37854980; PMCID: PMC10580209.

Alrasheed, S., H., Yousif, A., M., Moafa, M., A., Elmadina, A., E., M. & Alobaid, M. (2021). Sensitivity and Specificity of Sheard and Percival's Criteria for the Diagnosis of Young People with Near-heterophoria. *Open Access Macedonian Journal of Medical Sciences.* 9(B). pp. 1128-1134. DOI:10.3889/oamjms.2021.6399.

Alvarez, T. L., Vicci, V. R., Alkan, Y., Kim, E. H., Gohel, S., Barrett, A. M., … Biswal, B. B. (2010). Vision Therapy in Adults with Convergence Insufficiency: Clinical and Functional Magnetic Resonance Imaging Measures. *Optometry and Vision Science.* 87(12), 985–1002. doi: 10.1097/OPX.0b013e3181fef1aa. PMID: 21057347; PMCID: PMC3134155.

Alvarez, T. L., Scheiman, M., Santos, E. M., Yaramothu, C. & d'Antonio-Bertagnolli, J. V. (2020). Convergence Insufficiency Neuro-mechanism in Adult Population Study Randomized Clinical Trial: Clinical Outcome Results. *Optometry and Vision Science*. 97 (12), 1061-1069. doi: 10.1097/OPX.0000000000001606.

Anderson, H. A., Manny, R. E., Cotter, S.A., Mitchell, G. L. & Irani, J. A. (2010). Effect of Examiner Experience and Technique on the Alternate Cover Test. *Optometry and Vision Science*. 87, NO. 3, PP. 168–175.

Ancona, C., Stoppani, M., Odazio, V., La Spina, C., Corradetti, G., & Bandello, F. (2014). Stereo tests as a screening tool for strabismus: which is the best choice? *Clinical Ophthalmology.* (8), 2221-2227. doi: 10.2147/OPTH.S67488. PMID: 25419114; PMCID: PMC4235497.

Antona, B., Barrio, A., Barra, F., Gonzalez, E. & Sanchez, I. (2008). Repeatability and agreement in the measurement of horizontal fusional vergences. *Ophthalmic Physiological Optics*. 2008 Sep;28(5):475-91. doi: 10.1111/j.1475-1313.2008.00583.x. PMID: 18761485.

Antona, B., Barrio, A., Barra, F., Gonzalez, E. & Sanchez, I. (2015). Intraexaminer repeatability and agreement in stereoacuity measurements made in young adults. *International Journal of Ophthalmology*. 18;8(2), 374-81. doi: 10.3980/j.issn.2222-3959.2015.02.29. PMID: 25938059; PMCID: PMC4413594.

Archer, S. M., Miller, K. K., Helveston, E. M. & Ellis, F. D. (1986). Vergence amplitudes with random-dot stereograms. *British Journal of Ophthalmology*. 70(10), 718-723. doi: 10.1136/bjo.70.10.718. PMID: 3778855; PMCID: PMC1040814.

Askarizadeh, F., Heirani, M., Khorrami-Nejad, M,. Khabazkhoob, M. & Narooie-Noori, F. (2022). Effect of Vergence Facility Testing on Horizontal Fusional Reserves. *Optometry and Vision Science*. 1;99(1), 51-57. doi: 10.1097/OPX.0000000000001825. PMID: 34882605.

Aziz, S., Cleary, M., Stewart, H. K. & Weir, C. R. (2006). Are orthoptic exercises an effective treatment for convergence and fusion deficiencies? *Strabismus*. 14(4), 183-189. doi: 10.1080/09273970601026185. PMID: 17162439.

Babinsky, E., Sreenivasan, V. & Candy, T. R. (2015). Near heterophoria in early childhood. *Investigative Ophthalmology and Visual Science*, 56(2), 1406-1415. doi: 10.1167/iovs.14-14649. PMID: 25634983; PMCID: PMC4340430.

Bade, A., Boas, M., Gallaway, M., Mitchell, G. L., Scheiman M, Kulp, M.T … CITT Study Group. (2013). Relationship between clinical signs and symptoms of convergence insufficiency. *Optometry and Vision Science*. 90(9):988-95. doi: 10.1097/OPX.0000000000000012. PMID: 23958713; PMCID: PMC3929100.

Bailey, I. L. & Lovie, J. E. I. (1976) New design principles for visual acuity letter charts. *American Journal of Optometry and Physiological Optcs*. 53(11):740-5. doi: 10.1097/00006324-197611000-00006. PMID: 998716.

Banton, T. & Levi, D. M. (1991). Binocular summation in vernier acuity. *Journal of the Optical Society of America*. 8(4):673-80. doi: 10.1364/josaa.8.000673. PMID: 2045969.
Başgöze, Z., Mackey, A. P. & Cooper, E. A. (2018). Plasticity and Adaptation in Adult Binocular Vision. *Current Biology*. 17;28(24):R1406-R1413. doi: 10.1016/j.cub.2018.10.024. PMID: 30562537.

Birch, E., Williams, C., Drover, J., Fu, V., Cheng, C., Northstone, K. … Adams, R. (2008). Randot Preschool Stereoacuity Test: normative data and validity. *Journal of American Association for Pediatric Ophthalmology and Strabismus.* 12(1):23-6. doi: 10.1016/j.jaapos.2007.06.003. Epub 2007 Aug 27. PMID: 17720573; PMCID: PMC2577836.

Blake, R., Sloane, M. & Fox, R. (1981). Further developments in binocular summation. *Perception and Psychophysics*. 30(3), 266-276. doi: 10.3758/bf03214282. PMID: 7322802.

Borsting, E. J., Rouse, M. W., Mitchell, G. L., Scheiman, M., Cotter, S. A., Cooper, J. … London, R. (2003) Convergence Insufficiency Treatment Trial Group. Validity and reliability of the revised convergence insufficiency symptom survey in children aged 9 to 18 years. *Optometry and Vision Science*. 80(12):832-8. doi: 10.1097/00006324-200312000-00014. PMID: 14688547.

Cacho-Martínez, P., García-Muñoz, Á. & Ruiz-Cantero, M. T. (2010). Do we really know the prevalence of accomodative and nonstrabismic binocular dysfunctions? *Journal of Optometry*. 3(4):185–97. doi: 10.1016/S1888-4296(10)70028-5. Epub 2011 Jan 14. PMCID: PMC3974377.

Caltrider, N. & Jampolsky, A. (1983). Overcorrecting minus lens therapy for treatment of intermittent exotropia. *Ophthalmology*. 1983 Oct;90(10):1160-5. doi: 10.1016/s0161-6420(83)34412-2. PMID: 6657190.

Carlson, N. B. & Kurtz, D. (2004). Clinical procedures for ocular examination. 3rd ed. New York ; London: McGraw-Hill, pp. xv, 487.
Chin, N. B. (1969). Oculomotor imbalance in binocular vision and fixation disparity. *Archive of Ophthalmology.* 81(3), 450.

Chopin, A., Silver, M. A., Sheynin, Y., Ding, J. & Levi, D. M. (2021). Transfer of Perceptual Learning From Local Stereopsis to Global Stereopsis in Adults With Amblyopia: A Preliminary Study. *Frontiers in Neuroscience*. 2021 Sep 24;15:719120. doi: 10.3389/fnins.2021.719120. PMID: 34630011; PMCID: PMC8498040.

Clark, T. Y. & Clark, R. A. (2015). Convergence Insufficiency Symptom Survey Scores for Reading Versus Other Near Visual Activities in School-Age Children. *American Journal of Ophthalmology*. 160(5), 905-912.e2. doi: 10.1016/j.ajo.2015.08.008. Epub 2015 Aug 12. PMID: 26275474.

Clarke, W. N. & Noel, L. P. (1990). Stereoacuity testing in the monofixation syndrome. *Journal of American Association for Pediatric Ophthalmology and Strabismus*. 27, 161-3. doi: 10.3928/0191-3913-19900501-14. PMID: 2366128.

Convergence Insufficiency Treatment Trial Study Group. (2008). Randomized clinical trial of treatments for symptomatic convergence insufficiency in children. *Archives of Ophthalmology*. 126(10):1336-49. doi: 10.1001/archopht.126.10.1336. PMID: 18852411; PMCID: PMC2779032.

Conway, M. L., Thomas, J. & Subramanian, A. (2012). Is the aligning prism measured with the Mallett unit correlated with fusional vergence reserves? *PloS ONE*. 7(8):e42832. doi: 10.1371/journal.pone.0042832. Epub 2012 Aug 8. PMID: 22905174; PMCID: PMC3414500.

Cooper, J., Feldman, J. & Medlin, D. (1979). Comparing stereoscopic performance of children using the Titmus, TNO, and Randot stereo tests. *Journal of American Optometric Association.* 50(7):821-5. PMID: 500993.

Crone, R. A. & Hardjowijoto, A. (1979). What is normal binocular vision? *Documenta Ophthalmologica*. 47(1), pp. 163-199. doi: 10.1007/BF00145374. PMID: 520140.

Cumming, B. G. & DeAngelis, G. C. (2001). The physiology of stereopsis. *Annual Review Neuroscience*. 24, 203-238. doi: 10.1146/annurev.neuro.24.1.203. PMID: 11283310.

Demer, J. L. & Clark, R. A. (2019). Functional anatomy of extraocular muscles during human vergence compensation of horizontal heterophoria. *Journal of Neurophysiology*. 1;122(1), 105-117. doi: 10.1152/jn.00152.2019. Epub 2019 May 1. PMID: 31042451; PMCID: PMC6689778.

Evans, B. J. W. (2000). An open trial of the Institute Free-space Stereogram (IFS) exercises. *British Journal of Optometry*. Dispensing 8, 5–14.

Fawcett, S. L. & Birch E. E. (2003). Validity of the Titmus and Randot Circles Tasks in Children With Known Binocular Vision Disorders. *Journal of American Association for*

Pediatric Ophthalmology and Strabismus. 7(5), pp. 333-8. doi: 10.1016/s1091-8531(03)00170-8. PMID: 14566315.

Evans, B. J. W. (2001). Decompensated exophoria at near, convergence insufficiency and binocular instability: diagnosis and the development of a new treatment regimen. *Research Gate*. Chapter · December 2001. DOI: 10.1016/B978-0-7506-4713-7.50009-6 . https://www.researchgate.net/publication/290335151

Fawcett, S. L. (2005). An Evaluation of the Agreement Between Contour-Based Circles and Random Dot-Based Near Stereoacuity Tests. *Journal of American Association for Pediatric Ophthalmology and Strabismus*. 9(6), pp. 572-8. doi: 10.1016/j.jaapos.2005.06.006. PMID: 16414526.

Feng, Y., Jiang, J., Bai, X, Li. H, & Li, N. (2021). A randomized trial evaluating efficacy of overminus lenses combined with prism in the children with intermittent exotropia. *BMC Ophthalmology*. 6;21(1):73. doi: 10.1186/s12886-021-01839-0. PMID: 33549081; PMCID: PMC7866701.

Fogt, N., Baughman, B.,J. & Good, G. (2000). The effect of experience on the detection of small eye movements. *Optometry and Vision Science*. 77(12):pp. 670–4. doi: 10.1097/00006324-200012000-00014. PMID: 11147737.

Fortin, A., Ptito, A., Faubert, J. & Ptito, M. (2002). Cortical areas mediating stereopsis in the human brain: a PET study. *Neuro Report For Rapid Communication of Neuroscience Research.* 13(6), pp. 895-989. doi: 10.1097/00001756-200205070-00032. PMID: 11997709.

Frantz, K. A. (1997). Prescribing relieving prism for patients with binocular vision disorders. *Journal of Optometric Vision Development*. 28, 54-67.

Fricke, T. R. & Siderov, J. (1997). Stereopsis, stereotests, and their relation to vision screening and clinical practice. *Clinical and Experimental Optometry*. 80(5),165-172.

Frisby, J. P., Mein, J., Saye, A. & Stanworth, A. (1975). Use of randomdot sterograms in the clinical assessment of strabismic patients. *British Journal of Ophthalmology*. 59, 545-552. doi: 10.1136/bjo.59.10.545. PMID: 1191612; PMCID: PMC1017407.

Frisby, J. P. (1980). The Frisby Stereo test: amended instructions. *British and Irish Orthoptic Journal*. 37. https://www.researchgate.net/publication/247887091.

Frisén, L. & Lindblom, B. (1988). Binocular summation in humans: evidence for a hierarchic model. *The Journal of Physiology*. 402, 773-82. doi: 10.1113/jphysiol.1988.sp017233. PMID: 3236255; PMCID: PMC1191920.

Gall, R. & Wick, B. (2003). The symptomatic patient with normal phorias at distance and near: what tests detect a binocular vision problem? *Optometry*. 74(5):309-22. PMID: 12795318.

Gall, R., Wick, B. & Bedell, H. (1998). Vergence facility: establishing clinical utility. *Optometry and Vision Science*. 75(10):731-42. doi: 10.1097/00006324-199810000-00018. PMID: 9798213.

Gantz, L. & Bedell, H., E. (2010). Transfer of perceptual learning of depth discrimination between local and global stereograms. *Vision Research*. 23;50(18):1891-9. doi: 10.1016/j.visres.2010.06.011. Epub 2010 Jun 25. PMID: 20600234; PMCID: PMC2922406.

García-Muñoz, Á., Carbonell-Bonete, S., Cantó-Cerdán, M. & Cacho-Martínez, P. (2016). Accommodative and binocular dysfunctions: prevalence in a randomised sample of university students. *Clinical and Experimental Optometry.* 99(4), 313-21. doi: 10.1111/cxo.12376. Epub 2016 Mar 29. PMID: 27027297.

Garnham, L. & Sloper, J.J. (2006). Effect of age on adult stereoacuity as measured by different types of stereotest. *British Journal of Ophthalmology.* 90(1), 91-95. doi: 10.1136/bjo.2005.077719. PMID: 16361675; PMCID: PMC1856927.

Garzia, R. P. & Dyer, G. (1986). Effect of nearpoint stress on the horizontal forced vergence fixation disparity curve. *American Journal of Optometry and Physiological*

Optics. 63(11), 901-907. doi: 10.1097/00006324-198611000-00007. PMID: 3789081.

Gray, R. & Regan, D. (1998). Accuracy of estimating time to collision using binocular and monocular information. *Vision Research.* 38(4), 499-512.

Gray, L. S. (2008). The prescribing of prisms in clinical practice. *Graefe's Archive for Clinical and Experimental Ophthalmology*. 246(5), 627-9. doi: 10.1007/s00417-008-0799-2. *Electronic Publication*. Apr 1. PMID: 18379815; PMCID: PMC2292476.

Hamsher, K. S. (1978). Stereopsis and unilateral brain disease. *Investigative Ophthalmology and Vision Science.* 17(4), 336-43. PMID: 640781.

Hashemi, H., Nabovati, P., Khabazkhoob, M., Ostadimoghaddam, H., Doostdar, A., Shiralivand, E. … Yekta, A. (2017). The prevalence of convergence insufficiency in Iran: a population-based study. *Clinal and Experimental Optometry*. 100(6), 704-709. doi: 10.1111/cxo.12522. Epub 2017 Feb 21. PMID: 28222490.

Henson, D. B., & North, R. V. (1980). Adaptation to prism-induced heterophoria. *Retrieved from American Journal of Optometry and Physiological Optics*. 57(3), 129–137. http://www.ncbi.nlm.nih.gov/pubmed/7386573.

Horwood, A.M., Toor, S. & Riddell, P. M. (2014). Screening for convergence insufficiency using the CISS is not indicated in young adults. *British Journal of Ophthalmology*. 98(5):679-83. doi: 10.1136/bjophthalmol-2013-304533. Epub 2014 Feb 14. PMID: 24532798; PMCID: PMC3995238.

How do Different Treatments for the Vision Disorder, Convergence Insufficiency, Compare in Effectiveness? (2020). *Saudi Medical Journal*. 41(12). 1382–3. PMCID: PMC7841589.

Howard, I. P. & Rogers, B. J. (2012). *Perceiving in Depth.* New York: Oxford University Press. Volume 2 Stereoscopic Vision.

Jainta, S. & Jaschinski, W. (2002). Fixation disparity: binocular vergence accuracy for a visual display at different positions relative to the eyes. *Hum Factors*. 44(3), pp. 443-50. doi: 10.1518/0018720024497736. PMID: 12502161.

Jiménez, J.R., Olivares, J.L., Pérez-Ocón, F. & del Barco, L. J. (2000). Associated phoria in relation to stereopsis with random-dot stereograms. *Optometry and Vision Science*. 77(1):47-50. doi: 10.1097/00006324-200001000-00013. PMID: 10654858.

Jang, J. U., Jang, J. Y., Tai-Hyung, K. & Moon, H. W. (2017). Effectiveness of Vision Therapy in School Children with Symptomatic Convergence Insufficiency. *Journal of Ophthalmic and Vision Research*. 12(2),187-192. doi: 10.4103/jovr.jovr_249_15. PMID: 28540011; PMCID: PMC5423373.

Jaschinski, W. (2018). Individual objective versus subjective fixation disparity as a function of forced vergence. *PLoS ONE*. 13(7): e0199958. doi: 10.1371/journal.pone.0199958. PMID: 29980146; PMCID: PMC6035046.

Jenkins, T. C., Pickwell, L. D. & Yekta, A. A. (1989). Criteria for decompensation in binocular vision. *Ophthalmic and Physiological Optics*. 9(2):121-5. doi: 10.1111/j.1475-1313.1989.tb00830.x. PMID: 2622646.

Jiménez, J. R., Olivares, J. L., Pérez-Ocón. F. & del Barco LJ. (2000). Associated phoria in relation to stereopsis with random-dot stereograms. *Optometry and Vision Science.* 77(1):47-50. doi: 10.1097/00006324-200001000-00013. PMID: 10654858.

Johns, H. A., Manny, R. E., Fern, K. & Hu, Y. S. (2004). The intraexaminer and interexaminer repeatability of the alternate cover test using different prism neutralization endpoints. *Optometry and Vision Science*. 2004 Dec;81(12):939-46. Erratum in: *Optometry and Vision Science*. 82(2):159. PMID: 15592119.

Jones, R. K. & Lee, D. N. (1981). Why two eyes are better than one: The two views of binocular vision. *Journal of Experimental Psychology: Human Perception and Performanceю* 7(1), 30-40. doi: 10.1037//0096-1523.7.1.30. PMID: 6452501.

Julesz, B. (1978). Global stereopsis: cooperative phenomena in stereoscopic depth perception, in Perception, eds R. Held, H. W. Leibowitz, and H. L. Teuber (*New York, NY: Springer*), 215–256.

Kaiser, P.K. (2009). Prospective evaluation of visual acuity assessment: a comparison of snellen versus ETDRS charts in clinical practice (An AOS Thesis). *Transaction of the American Ophthalmological Society.* Dec;107:311-24. PMID: 20126505; PMCID: PMC2814576.

Karania, R. & Evans, B. J. W. (2006). The Mallett Fixation Disparity Test: influence of test instructions and relationship with symptoms. *Ophthalmic & Physiological Optics*. 26, 507-522. doi: 10.1111/j.1475-1313.2006.00385.x. PMID: 16918777.

Kommerell, G. & Kromeier, M. (2002). Prism correction in heterophoria. Prismenkorrektion bei heterophorie. *Ophthalmologe*. 99(1), 3–9. doi: 10.1007/pl00007112. PMID: 11840793.

Kriz, P. & Skorkovska, S. (2017). Distance associated heterophoria measured with polarized Cross test of MKH method and its relationship to refractive error and age. *Clinical Optometry*. 31;9, 55-65. doi: 10.2147/OPTO.S123436. PMID: 30214361; PMCID: PMC6095580.

Kromeier, M., Schmitt, C., Bach., M, & Kommerell, G. (2003) Stereoacuity versus fixation disparity as indicators for vergence accuracy under prismatic stress. *Ophthalmic and Physiological Optics*. 23(1):43-9. doi: 10.1046/j.1475-1313.2003.00089.x. PMID: 12535056. IV

Kundart, J. & Saad, R. A. (2016). Prescribing Comfortable Prisms to Individuals with Binocular Single Vision to Optimize Stereopsis. *College of Optometry*. Paper 13.

Lam, A. K., Tse, P., Choy, E. & Chung, M. (2002). Crossed and uncrossed stereoacuity at distance and the effect from heterophoria. *Ophthalmic and Physiological Optics*. 22(3), pp. 189-93. doi: 10.1046/j.1475-1313.2002.00030.x. PMID: 12090632.

Lambooij, M., Fortuin, M., Ijsselsteijn, W. A., Evans, B. J. W. E. & Heynderickx, I. (2011). Susceptibility to Visual Discomfort of 3-D Displays by Visual Performance Measures. *IEEE. Transactions on Circuits and Systems*. 21, 1913-1923/ DOI:10.1109/TCSVT.2011.2157193.

Landolt, E. (1886). The refraction and accommodation of the eye and their anomalies. *Edinburgh: Young J. Pentland*.

Lee, D. S., Kim, S. J. & Yu, Y.S. (2014a). The relationship between preoperative and postoperative near stereoacuities and surgical outcomes in intermittent exotropia. *British Journal of Ophthalmology*. 98, 1398–1403. doi: 10.1136/bjophthalmol-2013-304853. Epub 2014 May 13. PMID: 24825842.

Lee, J. & McIntyre, A. (1996). Clinical tests for binocular vision. *Eye*. 10 (Pt 2):282-5. doi: 10.1038/eye.1996.59. PMID: 8776461.

Lee, S. H., Moon, B. Y. & Cho, H. G. (2014b) Improvement of Vergence Movements by Vision Therapy Decreases K-ARS Scores of Symptomatic ADHD Children. *The Journal of Physical Therapy Science*. 26(2), 223-7. doi: 10.1589/jpts.26.223. Epub 2014 Feb 28. PMID: 24648636; PMCID: PMC3944293.

Lee, S. Y. & Koo, N. K. (2005).Change of stereoacuity with aging in normal eyes. *Korean Journal of Ophthalmology..* 19(2):136-9. doi: 10.3341/kjo.2005.19.2.136. PMID: 15988931.

Leibowitz, H. W., Shiina, K., Hennessy, R. T. (1972). Oculomotor adjustments and size constancy. *Percept Psychophys.* 12:497–500.

Leibowitz, H. W. & Moore, D. (1966). Role of changes in accommo dation and convergence in the perception of size. *Journal of the Optical Society of America.* 8:1120–1123.

Leshno, A., Stolovitch, C., Zloto, O., Meirovitch, S. B. & Mezad-Koursh D. (2021). Reduced stereoacuity as a predictor for clinically significant convergence insufficiency. *British Journal of Ophthalmology*. 105(1), 37-41. doi: 10.1136/bjophthalmol-2019-315208. Epub 2020 Mar 18. PMID: 32188680.

Levy, N. S. & Glick, E. B. (1974). Stereoscopic perception and Snellen visual acuity. *American Journal of Ophthalmology*. 78, 722-4. doi: 10.1016/s0002-9394(14)76312-3. PMID: 4415892.

London R. & Crelier R. S. (2006). Fixation disparity analysis: Sensory and motor approaches. *Optometry.* 77(12), 590-608. doi: 10.1016/j.optm.2006.09.006. PMID: 17157241.

Ludvigh, E. (1949). Amount of eye movement objectively perceptible to the unaided eye. American Journal of Ophthalmology. pp. 32:649.

Mallett, R. F. J. (1964). The investigation of heterophoria at near and a new Fixation Disparity technique. *Optician*. 148, 547-581.

Matthews, H. H., Hill, H. & Palmisano, S. (2012). Independent effects of local and global binocular disparity on the perceived convexity of stereoscopically presented faces in scenes. *Perception.* 41(2), pp. 168-174. doi: 10.1068/p7187. PMID: 22670345.

Mestre, C., Otero, C., Díaz-Doutón, F., Gautier, J. & Pujol, J. (2018). An automated and objective cover test to measure heterophoria. *PLoS One*. 1;13(11):e0206674. doi: 10.1371/journal.pone.0206674. PMID: 30383846; PMCID: PMC6211723.
Mishkin, M., Ungerleider, L. G. & Macko K. A. (1983). Object vision and spatial vision: Two cortical pathways. *Trends in Neuroscience*. 6, 414-417. doi: 10.1016/0166-2236(83)90190-X.

Momeni-Moghadam, H. M., Goss, D., Yekta, A. A. & Ehsani, M. (2013). Evaluation of fixation disparity curve parameters with the modified near Mallett unit in symptomatic and asymptomatic university students. *Iranian Red Crescent Medical Journal*. 15(11), e8572.

Momeni-Moghadam, H., Kundart, J., Ehsani, M. & Gholami, K. (2011). Stereopsis with TNO and Titmus Tests in Symptomatic and Asymptomatic University Students. *Journal of Behavioral Optometry.* 23(2), 35-39.

Montés-Micó R. (2001). Prevalence of general dysfunctions in binocular vision. *Annals of Ophthalmology*. 33, 205–208. doi.org/10.1007/s12009-001-0027-8.

Moon, B. Y., Kim, S. Y. & Yu, D. S. (2020). Receiver operating characteristic curve analysis of clinical signs for screening of convergence insufficiency in young adults.

PLoS One. 2020;15(1):e0228313. https://doi.org/10.1371/journal.pone.0228313. PMid:31978203.

Myklebust, A. & Riddell, P. (2016). Fusional stamina: An alternative to Sheard's criterion. *Scandinavian Journal of Optometry and Visual Science*. 9 (2). pp. 1-7.

Nabovati, P., Kamali, M., Mirzajani, A., Jafarzadehpur, E. & Khabazkhoob, M. (2020). The effect of base-in prism on vision-related symptoms and clinical characteristics of young adults with convergence insufficiency; a placebo-controlled randomised clinical trial. *Ophthalmic and Physiological Optics*. 40(1):8-16. doi: 10.1111/opo.12654. Epub 2019 Dec 3. PMID: 31797407.

Nakatsuka, C., Zhang, B., Watanabe, I., Zheng, J., Bi, H., Ganz, L. … Chino, Y. M. (2007). Effects of perceptual learning on local stereopsis and neuronal responses of V1 and V2 in prism-reared monkeys. *Journal of Neurophysiology*. 97, pp. 2612-26.
Ngan, J., Gross, D. & Despirito, J. (2005). Comparison of Fixation Disparity Curve Parameters Obtained with the Wesson and Saladin Fixation Disparity Cards. *Optometry and Vision Science*. 82(1), 69–74. PMID: 15630407.

North, R. V. & Henson, D. B. (1982). Effect of orthoptics upon the ability of patients to adapt to prism-induced heterophoria. *American Journal of Optometry and Physiological Optics*. 59(12):983-6. doi: 10.1097/00006324-198212000-00008. PMID: 7158656.

Ogle, K. N., Martens, T. G. & Dyer, A. J. (1967). Oculomotor Imbalance in Binocular Vision and Fixation Disparity. *Philadelphia: Lee and Febiger*. Cited in Schor CM. Vergence eye movements: basic aspects. Wenner-Gren International Symposium 37. Oxford: Pergamon Press, 1981: 83–91.

Ohlsson, J., Villarreal, G., Abrahamsson, M., Cavazos, H., Sjöström, A. & Sjöstrand, J. (2001). Screening merits of the Lang II, Frisby, Randot, Titmus, and TNO stereo tests. *Journal of American Assosiation of Pediatric Ophthalmology and Strabismus*. 5(5), 316-22. doi: 10.1067/mpa.2001.118669. PMID: 11641643.

O'Leary, C. I. & Evans, B. J. W. (2003). Criteria for prescribing optometric interventions: literature review and practitioner survey. Op*hthalmic and Physiological Optics*. 23(5), 429–439. doi: 10.1046/j.1475-1313.2003.00137.x. PMID: 12950889.

O'Leary, C. I. & Evans, B. J. (2006). Double-masked randomised placebo-controlled trial of the effect of prismatic corrections on rate of reading and the relationship with symptoms. *Ophthalmic and Physiological Optics*. 26(6), 555-65. doi: 10.1111/j.1475-1313.2006.00400.x. PMID: 17040419.

Otto, J. M., Kromeier, M., Bach, M. & Kommerell, G. (2008a), Do dissociated or associated phoria predict the comfortable prism? *Graefe's Archives of Clinical and Experimental Ophthalmology*. 2008 May;246(5):631-9. doi: 10.1007/s00417-008-0798-3. Epub 2008 Apr 1. PMID: 18379816; PMCID: PMC2292470.

Otto, J. M. N., Bach, M. & Kommerell, G. (2008b). The prism that aligns fixation disparity does not predict the self-selected prism. *Ophthalmic and Physiological Optics*. 28(6), 550-7. doi: 10.1111/j.1475-1313.2008.00599.x. PMID: 19076557.

Pageau, M., Saint-Amour, D. & de Guise, D. (2011). Local and global stereopsis in children with microstrabismus. *Canadian Journal of Ophthalmology*. 46(3), 271-5. doi: 10.1016/j.jcjo.2011.05.002. Epub 2011 May 27. Erratum in: *Canadian Journal of Ophthalmology*. 2011 Oct;46(5):450. PMID: 21784214.

Pang, Y., Teitelbaum, B. & Krall, J. (2012). Factors associated with base-in prism treatment outcomes for convergence insufficiency in symptomatic presbyopes. *Clinical and Experimental Optometry*. 95(2):192-7. doi: 10.1111/j.1444-0938.2011.00693.x. Epub 2012 Jan 11. PMID: 22233325.

Parmar, K. R., Dickinson, C. & Evans, B. J. W. (2019). Does an iPad fixation disparity test give equivalent results to the Mallett near fixation disparity test?. *Journal of Optometry*. 12(4), 222–231. doi: 10.1016/j.optom.2019.03.002. Epub 2019 Sep 7. PMID: 31501055; PMCID: PMC6978586.

Payne, C. R., Grishmian, D. & Thomas, K. L. (1974). A Clinical Evaluation of Fixation Disparity. *Optometry and Vision Science*. 51(2), 88-90.

Pediatric Eye Disease Investigator Group (PEDIG). (2023). A Pilot Randomized Clinical Trial of Base-in Relieving Prism Spectacle Treatment for Intermittent Exotropia. *Optometry and Vision Science* ():10.1097/OPX.0000000000002039, July 3, 2023. | DOI: 10.1097/OPX.0000000000002039.

Percival, A. S. & Fox, L. W. (1922). Discussion On The Clinical Significance And Treatment Of Heterophoria. *The British Medical Journal*. 2(3235), 1249-1256.

Pickwell, D., Jenkins, T. & Yekta, A. A. (1987). The effect on fixation disparity and associated heterophoria of reading at an abnormally close distance. *Ophthalmic and Physiological Optics.* 7(4), 345-347. PMID: 3454908.

Pickwell L. D., Kaye, N. A. & Jenkis, T. C. A. (1991). Distance and near readings of associated heterophoria taken on 500 patients. *Ophthalmic and Physiological Optics.* 11(4):291-6. PMID: 1771065.

Policar, O. (2018). Selected methods of heterophoria examination and their comparison. *University of Latvia, Optics and Optometry Forum. CTU in Prague*. 23-
Portela-Camino, J. A. (2021). Advances in Research in Binocular Vision. *Journal of Optometry*. 14(3), 227-228. doi: 10.1016/j.optom.2021.06.001. PMID: 34176573; PMCID: PMC8258125.

Przekoracka-Krawczyk, A., Michalak, K. P. & Pyżalska, P. (2019). Deficient vergence prism adaptation in subjects with decompensated heterophoria. *PLoS ONE*. 18;14(1):e0211039. doi: 10.1371/journal.pone.0211039. PMID:30657792; PMCID: PMC6338415.

Ptito, A., Zatorre, R. J., Larson, W. L. & Tosoni, C. (1991). Stereopsis after unilateral anterior temporal lobectomy. Dissociation between local and global measures. *Brain a Journal of Neurology*. 114(3), 1323-33. doi: 10.1093/brain/114.3.1323. PMID: 2065253.

Qiu, F. T. & von der Heydt, R. (2005). Figure and ground in the visual cortex: v2 combines stereoscopic cues with gestalt rules. *Neuron*. 7;47(1):155-66. doi: 10.1016/j.neuron.2005.05.028. PMID: 15996555; PMCID: PMC1564069.

Rae, S. (2015). Evidence-based management of convergence insufficiency. *Optometry in Practice*. 16(1), 1-10.

Reineck, R. D. & Simons, K. (1974). A new stereoscopic test for amblyopia screening. *American Journal of Ophthalmology*. 78, 714-21.

Richards, W. (2009). Configuration stereopsis: A new look at the depth-disparity relation. *Spatial Vision*. 22(1), 91-103. doi: 10.1163/156856809786618493. PMID: 19055889.

Rinsky, N. (2017). Stereoacuity measured with Titmus, Randot and TNO stereotests as an indicator of decompensated heterophoria. *MRes thesis, Cardiff University, School of Optometry and Vision Sciences.*

Rouse, M. W., Borsting, E. J., Mitchell, G. L., Scheiman, M., Cotter, A., Cooper, J. … Convergence Insufficiency Treatment Trial Group (2004). Convergence Insufficiency Treatment Trial Group. Validity and reliability of the revised convergence insufficiency symptom survey in adults. *Ophthalmic and Physiological Optics*. 24(5). 384-90. doi: 10.1111/j.1475-1313.2004.00202.x. PMID: 15315652.

Rowe, F. J., Noonan, C. P., Freeman, G. & DeBell, J. (2009). Intervention for intermittent distance exotropia with overcorrecting minus lenses. *Eye (Lond).* 2009 Feb;23(2):320-5. doi: 10.1038/sj.eye.6703057. Epub 2007 Dec 7. PMID: 18064054.

Rutstein, R. P. & Eskridge, B. (1984). Stereopsis in small-angle strabismus. *American Journal of Optometry and Physiological Optics*. 61, 491-8.

Rutstein R. P., Fuhr, P. & Schaafsma, D. (1994). Distance stereopsis in orthophores, heterophores, and intermittent strabismics. *Optometry and Vision Science.* 71, pp. 415-421. doi: 10.1097/00006324-199407000-00001. PMID: 7970556.

Saladin, J. J. (2005) Stereopsis from a performance perspective. Optometry and Vision Science. 82(3):186-205. doi: 10.1097/01.opx.0000156320.71949.9d. PMID: 15767874.

Santos, E. M., Yaramothu, C. & Alvarez, T. L. (2018). Comparison of symmetrical prism adaptation to asymmetrical prism adaptation in those with normal binocular vision.

Vision Research. 149:59-65. doi: 10.1016/j.visres.2018.06.004. Epub 2018 Jun 28. PMID: 29940191; PMCID: PMC6174079.

Scheiman, M., Kulp, M. T., Cotter, S. A., Lawrenson, J. G., Wang, L. & Li, T. (2020). Interventions for convergence insufficiency: a network meta-analysis. *Cochrane Database of Systemic Review*. 2;12(12):CD006768. doi:10.1002/14651858.CD006768.pub3. PMID: 33263359; PMCID: PMC8092638.

Scheiman, M., Mitchell, G. L., Cotter, S., Kulp, M. T., Cooper, J. & Rouse, M. … Wensveen, J. (2005). A randomized clinical trial of vision therapy/orthoptics versus pencil pushups for the treatment of convergence insufficiency in young adults. *Optometry and Vision Science*. 82(7). 583-95. doi: 10.1097/01.opx.0000171331.36871.2f. PMID: 16044063.

Scheiman, M., Kulp, M. T., Cotter, S., Mitchell, G. L., Gallaway, M., Boas, M. … Tamkins, S. (2010). Vision Therapy/Orthoptics for Symptomatic Convergence Insufficiency in Children: Treatment Kinetics. *Optometry and Vision Science*, 87 (8), 593-603. doi: 10.1097/OPX.0b013e3181e61bad.

Scheiman, M., Kulp, M.T., Cotter, S.A., Lawrenson, J.G., Wang, L., & Li, T. (2020). Interventions for convergence insufficiency: a network meta-analysis. *Cochrane Database of Systematic Review*. 2;12(12):CD006768. doi: 10.1002/14651858.CD006768.pub3. PMID: 33263359; PMCID: PMC8092638.

Schor, C. M. (1979). The influence of rapid prism adaptation upon fixation disparity. Vision Research. 19(7):757-65. doi: 10.1016/0042-6989(79)90151-2. PMID: 483594.

Schroth, V., Joos, R., Alshuth, E. & Jaschinski, W. (2019). Effects of aligning prisms on the objective and subjective fixation disparity in far distance. *Journal of Eye Movment Research*. 11;12(4):10.16910/jemr.12.4.8. doi: 10.16910/jemr.12.4.8. PMID: 33828739; PMCID: PMC7880133.

Sheard, S. (1930). Zones of ocular comfort. *American Journal of Optometry.* 7, 9-25.
Sheard, S. (1934). The Prescription of Prisms. *American Journal of Optometry.* 11(10), 364-378.

Sheedy, J. E. & Saladin, J. J. (1978a). Association of symptoms with measures of oculomotor deficiencies. *Optometry & Vision Science*. 55(10), 670-676. doi: 10.1097/00006324-197810000-00002. PMID: 747192.

Sheedy, J. E., & Saladin, J. J. (1978b). Validity of diagnostic criteria and case analysis in binocular vision disorders. Am*erican Journal of Optometry and Physiological Optics*. Oct;55(10):670-6.

Shin, H. S., Park, S. C. & Maples W. C. (2011). Effectiveness of vision therapy for convergence dysfunctions and long-term stability after vision therapy. *Ophthalmic and Physiological Optics*.31(2): 180-9. doi: 10.1111/j.1475-1313.2011.00821.x. PMID: 21309805.

Schroth, V., Prenat, O., Vlasak, N. & Crelier, R. (2017). Hoya Eyagenius: New Metjod forMeasuring and Correcting Fixation Disparity. *Proceedings of the Latvian Academy of Sciences Section B Natural Exact and Applied Sciences*. 71(5), 392-296.

Schweers, M. A. & Baker, J. D. (1992). Comparison of Titmus and two Randot tests in monofixation. *Amerinan Orthoptic Journal*. 42, 135-42.

Simons, K. & Reinecke, R. D. (1974). A reconsideration of amblyopia screening and stereopsis. *American Journal of Ophthalmology*. 78, 707-13. doi: 10.1016/s0002-9394(14)76310-x. PMID: 4411731.

Sreenivasan, V., Irving, E. L., & Bobier, W. R. (2012). Effect of heterophoria type and myopia on accommodative and vergence responses during sustained near activity in children. *Vision Research*. 15;57:9-17. doi: 10.1016/j.visres.2012.01.011. Epub 2012 Feb 1. PMID: 22322001.

Stavis, M., Murray, M., Jenkins, P., Wood, R., Brenham, B. & Jass, J. (2002). Objective improvement from base-in prisms for reading discomfort associated with mini-convergence insufficiency type exophoria in school children. *Binocular Vision and Strabismus Quarterly*. 17: 135–142. PMID: 12067271.

Stidwill, D. & Fletcher, R. (2011). Normal Binocular Vision: Theory, Investigation and Practical Aspects 1st Edition. *Wiley-Blackwell, A John Wilew & Sons, LTD., Publication*.

Summers, A. I., Morrison, D. G., Chandler, D. L., Henderson, R. J., Chen, A. M., Leske, D. A. … Cotter, S. A. (2023) Pediatric Eye Disease Investigator Group. A Pilot Randomized Clinical Trial of Base-in Relieving Prism Spectacle Treatment of Intermittent Exotropia. *Optometry and Vision Science*. 1;100(7):432-443. doi: 10.1097/OPX.0000000000002039. Epub 2023 Jul 1. PMID: 37399233; PMCID: PMC10534203.

Swenor, B. K., Wang, J., Varadaraj, V., Rosano, C., Yaffe, K., Albert, M., Simonsick, E. M. (2019). Vision Impairment and Cognitive Outcomes in Older Adults: The Health ABC Study. *The Journal of Gerontology. Series A, Biological Science and Medical Science*. 16;74(9):1454-1460. doi: 10.1093/gerona/gly244. Erratum in: J Gerontol A Biol Sci Med Sci. 2019 Aug 16;74(9):1484. doi: 10.1093/gerona/gly285. PMID: 30358809; PMCID: PMC6696724.

Takada, R., Matsumoto, F., Wakayama, A., Numata, T., Tanabe, F., Abe, K. & Kusaka, S. (2021). Efficacies of preoperative prism adaptation test and monocular occlusion for detecting the maximum angle of deviation in intermittent exotropia. *BMC Ophthalmology*. 21;21(1):304. doi: 10.1186/s12886-021-02060-9. PMID: 34418996; PMCID: PMC8379893.

Tang, S. T. & Evans, B. J. (2007). The Near Mallett Unit Foveal Suppression Test: a cross-sectional study to establish test norms and relationship with other optometric tests. *Ophthalmic and Physiological Optics*. 27(1):31-43. doi: 10.1111/j.1475-1313.2006.00453.x. PMID: 17239188.

Teitelbaum, B., Pang, Y. & Krall, J. (2009). Effectiveness of base in prism for presbyopes with convergence insufficiency. *Optometry and Vision Science*. 86(2):153-6. doi: 10.1097/OPX.0b013e318194e985. PMID: 19156012.

Thiagarajan, P. (2008). Effect of vergence adaptation and positive fusional vergence training on oculomotor parameters. *Master thesis, Waterloo, Ontario, Canada*,: University of Waterloo.

Tiwari, N., Paul, U. & Paritekar, P. (2017). Retrospective study of effect of therapy on computer vision syndrome patients having convergence insufficiency. *Kerala Journal of Ophthalmology*. 29(2), 97-101. dio: 10.4103/kjo.kjo_77_17.

Ukwade, M. T., Bedell, H.E. & Harwerth, R. S. (2003) Stereopsis is perturbed by vergence error. *Vision Research*. 43, 181–93. doi: 10.1016/s0042-6989(02)00408-x. PMID: 12536140.

Vancleef, K., Read, J. C. A., Herbert, W., Goodship, N., Woodhouse, M. & Serrano-Pedraza, I. (2017). Overestimation of stereo thresholds by the TNO stereotest is not due to global stereopsis*. Ophthalmic and Physiologocal Optics*. 37(4), pp. 507-520. doi: 10.1111/opo.12371. Epub 2017 Mar 23. PMID: 28337792; PMCID: PMC5516234.

van Doorn, L. L., Evans, B. J., Edgar, D. F. &Fortuin, M. F. (2014). Manufacturer changes lead to clinically important differences between two editions of the TNO stereotest. *Ophthalmic and Physiological Optics*. 34(2):243-9. doi: 10.1111/opo.12101. Epub 2013 Dec 19. PMID: 24355036.

von Noorden, G. K. (1990). Binocular Vision and Ocular Motility: Theory and Management of Strabismus. *MO: Mosby, A Harcourt Health Sciences Company. St. Louis London Philadelphia Sydney Toronto.* 191–197.

Wang, B. & Kuwera, E. (2022). Vision Therapy: A Primer and Caution for Pediatricians. *Children (Basel).* 30;9(12):1873. doi: 10.3390/children9121873. PMID: 36553317; PMCID: PMC9777217.

Widmer, D. E., Oechslin, T. S., Limbachia, C., Kulp, M. T., Toole, A. J., Kashou. … Fogt, N. (2018). Post-therapy Functional Magnetic Resonance Imaging in Adults with Symptomatic Convergence Insufficiency. *Optometry and Vision Science*. 95, 505–514. doi:10.1097/OPX.0000000000001221.

Wajuihian, S. O. (2020). Correlations between clinical measures and symptoms: Report 1: Stereoacuity with accommodative, vergence measures, and symptoms. *Journal of Optometry*. 13(3):171-184. doi: 10.1016/j.optom.2020.02.002. Epub 2020 May 29. PMID: 32475793; PMCID: PMC7301208.

Westman, M. & Liinamaa, M. J. (2012). Relief of asthenopic symptoms with orthoptic exercises in convergence insufficiency is achieved in both adults and children. *Journal of Optometry*. 5(2) 62–7. doi:10.1016/j.optom.2012.03.002. Epub 2012 Apr 18. PMCID: PMC3861273.

Wong, L. C., Rosenfield, M., & Wong, N. N. (2001). Vergence adaptation in children and its clinical significance. *Binocular Vision and Strabismus Quarterly*. 16, 29–34.

Winn, B., Gilmartin, B., Sculfor, D. L. & Bamford, J. C. (1994). Vergence adaptation and senescence. *Optometry and Vision Science*. 71(12). pp. 797-800. doi: 10.1097/00006324-199412000-00011. PMID: 7898888.

Woodman, W., Young, M., Kelly, K., Simoens, J. & Yolton, R. L. (1990). Effects of monocular occlusion on neural and motor response times for two-dimensional stimuli. *Optometry and Vision Science*.67(3): pp.169-78. doi: 10.1097/00006324-199003000-00005. PMID:2181363.

Wu, Y., Sreenivasan, V., Babinsky, E. E. & Candy, T., R. (2016). Adaptation of horizontal eye alignment in the presence of prism in young children. *Journal of Visualization*. 2016 Aug 1;16(10):6. doi: 10.1167/16.10.6. PMID: 27548084; PMCID: PMC5833321.

Yekta, A. A., Jenkins, T. & Pickwel D. (1987). The clinical assessment of binocular vision before and after a working day. *Ophthalmic and Physiological Optics*. 7(4), 349-352.

Yekta, A. A., Pickwell, L. D. & Jenkis, T. C. A. (1989). Binocular vision, age and symptoms. *Ophthalmic and Physiological Optics*. 9, 115–120. doi: 10.1111/j.1475-1313.1989.tb00829.x. PMID: 2622645.

Zhao, L. & Wu, H. (2019). The difference in stereoacuity testing: contour-based and random dot-based graphs at far and near distances*. Annals of Translation Medicine.* 7(9):193. doi: 10.21037/atm.2019.03.62. PMID: 31205911; PMCID: PMC6545306.

11.2. Bibliography

Benjamin, W., J. & Borish, I., M. (2006). *Borish's clinical refraction*. 2nd ed. St. Louis, Miss.: Butterworth Heinemann/Elsevier.

Evans, B. J. W. (2007). *Pickwell's Binocular Vision Anomalies.* 5th ed. *Elsevier Ltd.*

Goss, D., A. (1995). Ocular Accommodation, Convergence, and Fixation Disparity: A Manual of Clinical Analysis. *Butterworth-Heinemann.* 2nd edition. ISBN-13 978-0750694971

Ogle, K., N. (1950). Researches in binocular vision. (1950). *Saunders.*

Rowe, F., J. (2012). *Clinical orthoptics.* 3th ed. Willey Blackwell, 22.

Scheiman M. & Wick B. (2002). Clinical management of binocular vision. 2nd ed. USA: Lippincott-Raven; pp. 224.

Scheiman, M. & Wick, B. (2008). *Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye Movement Disorders. 3rd* ed.

Schor, C., M. & Ciuffedra, K., J. (1983). Vergence eye movements: Basic and clinical aspects. *Butterworth-Heinemann.* ISBN-13 978-0409950328

von Noorden, G., K. & Campos, E., C. (2002). Binocular Vision and Ocular Motility: Theory and Management of Strabismus. *Mosby.* 6th edition

11.3. Recent Reviews

Fogt, N. (2023) Topical Review: Methodological Variables in Clinical and Laboratory Measurements of Fixation Disparity. *Optometry and Vision Science*. 1;100(8):572-594. doi: 10.1097/OPX.0000000000002041. PMID: 37436811.

Appendix 1a
Consent to Participate in a Research Study

The title of Study: Evidence based criteria diagnosis and management of decompensating heterophoria

Investigator: Natalia Rinsky +7-967-048-33-43 +972544444145

Introduction

- You are being asked to participate in a research study of investigation of the results of stereoacuity with four different tests that are used among symptomatic (decompensated heterophoria) and asymptomatic (compensated heterophoria).
- You were selected as a possible participant because your Myopia, hyperopia, astigmatism and anisometropia (spherical equivalent) lower than -6.00, +6.00 and 1.50 diopters, respectively, you have no history of significant eye trauma, you have absence of significant retinal diseases, head injury, or neurological disorders, developmental delays, no history of ocular trauma, you have a normal eye health and your age is between 18-35.
- You are asked to read this form and ask any questions that you may have before agreeing to participate in this study.

Purpose of Study

- The purpose of the study is to determine whether the level of the stereo acuity measured with three different tests can be used to differentiate between compensated and decompensated heterophoria.
- This research may be published in a professional journal.

Description of the Study Procedures

There will be up to four appointments.
The procedures that are included in the study are:

- Routine refraction with trial frame/phoropter
- Best correction with trial frame/phoropter

- The near visual acuity
- Binocular Vision assessment
- Unilateral and Alternating Cover test for distance and near
- Fusional reserves using the prism bar for distance and near
- Fixation disparity with Mallett unit
- The experimental part, the stereoacuity measurement with different stereotests. All the stereoacuity measurements (Titmus, Randot, TNO and Frisby) will be repeated 4 times with a 2 minutes' interval between each measurement.
- Then a prism will be placed before one eye and the stereoacuity measurements will be repeated.
- Then another prism will be placed before one eye and the stereoacuity measurements will be repeated once again in the same manner.
- You may be asked to use an optical correction with Fresnel prism for one and a half month long and then it will be replaced by another optical correction with Fresnel prism for another one and a half month. You will be asked to fill the modified CISS questionnaire after each period.

Risks/Discomforts of Being in this Study

- There are no reasonable foreseeable (or expected) risks. There may be unknown risks.

Confidentiality

- This study is anonymous. No information about your identity will be collected or retained.

Right to Refuse or Withdraw

- The decision to take part in this study is entirely up to you. You may refuse to participate in this study at any time without affecting your relationship with the investigators of this study. Your decision not to participate will not result in any loss or benefits to which you are otherwise entitled. You have the right not to answer any single question, as well as to withdraw completely from the interview at any point during the research process; additionally, you have the right to request that the interviewer not uses any of your interview material.

Right to Ask Questions and Report Concerns

- You have the right to ask questions about this research study at any time and to have those questions answered by me before, during or after the research. If you have any further questions about the study, at any time feel free to contact me, Natalia Rinsky at 1205660@gmail.com or by telephone +7-903-120-56-60. If you like, a summary of the results of the research, it will be sent to you.

Consent

- Your signature below indicates that you have decided to volunteer as a research participant for this particular research, and that you have read and understood the information provided above. You have asked all the questions you have and you have got all the answers for the questions asked. You will be given a signed and dated copy of this form to keep.

☐ I do want to have the study results. I want it being sent to the next email address:

_____

Subject's Name (print): _____

Subject's Signature: _____ Date: _____

Date:

Investigator's Signature: _____ _____

Appendix 1b
Согласие на участие в клиническом исследовании

Название исследования: Диагностика и лечение декомпенсирующей гетерофории по критериям, основанным на фактических данных.

Исследователь: Наталья Ринская +7-967-048-33-43 +972544444145

Введение

- Вас просят принять участие в научном исследовании по изучению результатов остроты зрения с помощью четырех различных тестов, которые используются среди симптоматических (декомпенсированная гетерофория) и бессимптомных (компенсированная гетерофория).
- Вы были выбраны в качестве возможного участника, поскольку ваша близорукость, дальнозоркость, астигматизм и анизометропия (сферический эквивалент) ниже -6,00, +6,00 и 1,50 диоптрий соответственно, у вас нет в анамнезе серьезных травм глаз, у вас нет серьезных заболеваний сетчатки, травма головы или неврологические расстройства, задержка развития, отсутствие травм глаз в анамнезе, у вас нормальное здоровье глаз и ваш возраст от 18 до 35 лет.
- Вам предлагается прочитать эту форму и задать любые вопросы, которые могут у вас возникнуть, прежде чем дать согласие на участие в этом исследовании.

Цель исследлвания

- Цель исследования – определить, можно ли использовать уровень остроты стереозрения, измеренный с помощью трех разных тестов, для дифференциации компенсированной и декомпенсированной гетерофории.
- Это исследование могут быть опубликованы в профессиональном журнале..

Описание процедур исследования

Вас ждут до четырех встреч.

В исследование входят следующие процедуры:

- Обычная рефракция с пробной оправой/фороптером
- Лучшая коррекция с помощью с пробной оправой/фороптером
- Острота зрения вблизи
- Односторонний и альтернирующий “ковер тест” при зрении вдаль и при зрении вблизи
- Фузионные резервы с применением призматической линейки при зрении вдаль и при зрении вблизи
- Фиксационная диспаратность с использованием Mallett unit
- Экспериментальная часть, измерение стереозрения с применением разных стереотестов. Все измерения стереоскопического зрения (Titmus, Randot, TNO and Frisby) будут повторены 4 раза с паузой в 2 минуты между каждым измерением
- Затем будет установлена призма перед одним глазом и стереозрение будет измерено повторно
- Затем другая призма будет установлена перед одним глазом и измерение стереозрения будет повторено тем-же способом
- Вас попросят использовать оптическую очковую коррекцию зрения с призмой Френеля на протяжении 1,5 месяцев, а потом эта коррекция будет заменена на другую коррекция с Френель на 1,5 месяцев. После каждого периода вас попросят заполнить опросник.

Риски/дискомфорты участия в этом исследовании

- Не существует разумных предсказуемых (или ожидаемых) рисков. Могут быть неизвестные риски.

Конфиденциальность

Это исследование является анонимным. Никакая информация о вашей личности не будет собрана или сохранена.

Право на отказ

Решение принять участие в этом исследовании полностью зависит от вас. Вы можете отказаться от участия в этом исследовании в любое время, не затрагивая при этом ваши отношения с исследователями. Ваше решение не участвовать не приведет к каким-либо потерям или преимуществам, на которые вы в противном случае имеете право. Вы имеете право не отвечать ни на один вопрос, а также полностью отказаться от интервью в любой момент процесса исследования; кроме того, вы имеете право потребовать, чтобы интервьюер не использовал какие-либо материалы вашего интервью.

Право задавать вопросы и сообщать о проблемах

Вы имеете право в любое время задавать вопросы об этом исследовании и получать от меня ответы на эти вопросы до, во время или после исследования. Если у вас возникнут дополнительные вопросы по поводу исследования, в любое время обращайтесь ко мне, Наталье Ринской по электронной почте 1205660@gmail.com или по телефону +7-903-120-56-60. Если хотите, краткое изложение результатов исследования будет вам отправлено.

Согласие

Ваша подпись ниже означает, что вы решили стать волонтером в качестве участника данного конкретного исследования и что вы прочитали и поняли информацию, представленную выше. Вы задали все вопросы, которые у вас есть, и получили все ответы на заданные вопросы. Вам будет предоставлена подписанная и датированная копия этой формы, которую вы сможете сохранить.

☐ Я хочу получить результаты исследования. Я хочу, чтобы оно было отправлено на следующий адрес электронной почты:_____

Имя участника (печатными буквами): _____

Подпись участника: Дата:

_____ _____

Дата:

Подпись исследователя: _____ _____

Appendix 2a

A modified CISS questionnaire

First name: _____ Last name: _____ Date:_____

Please check the appropriate box for each symptom.

Phoria compensation status questionnaire						
		Never	Rarely	Sometimes	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 (that come on) when reading or doing close work?					
4	Do you feel sleepy when reading or doing close work?					
5	Do you loose concentration when reading or doing close work?					
6	Do you have trouble remembering when reading or doing close work?					
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 loose your place while reading or doing close work?					
15	Do you have to re-read the same line of words when reading?					

(Never = 0; Rarely= 1; Sometimes=2; Often= 3; Always= 4). Questionnaire scores will be analysed according to the level of phoria compensation to determine scores indicating decompensation.

Total score _____

Appendix 2b

Опросник

Фамилия: _____ Имя: _____ Дата:_____

Пожалуйста, отметьте соответствующее поле в отношении каждого симптома.

Опросник уровня компенсации фории						
		Никогда	Редко	Иногда	Часто	Всегда
1	Чувствуете ли вы усталость глаз при чтении или работе на близких расстояниях?					
2	Чувствуете ли вы дискомфорт при чтении или работе на близких расстояниях?					
3	Испытываете ли вы головную боль при чтении или работе на близких расстояниях?					
4	Испытываете ли вы сонливость при чтении или работе на близких расстояниях?					
5	Теряете ли вы концентрацию при чтении или работе на близких расстояниях?					
6	Испытываете ли вы затруднения с памятью при чтении или работе на близких расстояниях?					
7	Испытываете ли вы двоение при чтении или работе на близких расстояниях?					
8	Наблюдаете ли вы смещение или прыжки слов по странице при чтении или работе на близких расстояниях?					
9	Испытываете ли вы замедленное чтение?					
10	Испытываете ли вы боль в глазах при чтении или работе на близких расстояниях?					
11	Do your eyes ever feel sore when reading or doing close work?					
12	Испытываете ли вы пульсацию вокруг глаз при чтении или работе на близких расстояниях?					
13	Испытываете ли вы нечеткость или измение фокусировки при чтении или работе на близких расстояниях?					
14	Теряетели вы строчку при чтении или работе на близких расстояниях?					
15	Требуется ли вам повторно прочесть одну и ту же строчку при чтении или работе на близких расстояниях?					

(Never = 0; Rarely= 1; Sometimes=2; Often= 3; Always= 4). Questionnaire scores will be analysed according to the level of phoria compensation to determine scores indicating decompensation.

Результат _____

Appendix 3

Clinical Tests Methodology

3.1 Cover Test (CT)

Unilateral CT was performed to differentiate decompensated heterophoria from decompensated heterophoria. An alternating CT was performed using a prism bar to measure the deviation angle. The subject was fixated on a stick held at 40cm. A prism bar was increased gradually until the recovery movement changed its direction (from nasal to temporal). The highest prism before the direction change in the recovery movement was considered a deviation angle. If the recovery movement on one of the steps was nasal and on the next step temporal, when the steps on the prism bar were more than one PD, then the value of the deviation angle was recorded between these steps on the prism bar. For example, if with 12 PD on the prism bar, there was a nasal movement and with 14 temporal, then the deviation angle was considered to be 13 PD.

The CT was performed to assess the presence and the magnitude of phoria or tropia and the presence or absence of motor fusion (Carlson & Kurtz, 2004). Moreover, the quality of the recovery movement of the patient's eyes is a good basis for differentiating whether the phoria is compensated or not. If it is compensated, the recovery will be quick and smooth. On the other hand, a slow, jerking or hesitant recovery will indicate decompensation. The motor fusion was recorded since it was one of the phoria compensation status criteria.

3.2 Near Fixation Disparity (FD) using Mallett Unit

The test was performed at a 40 cm. distance while the subject was wearing a polarised filter over the trial frame if the participant had a refractive error and without optical correction if the participant had no refractive error. The filters contributed to dichoptic stimulation; the right eye saw only the upper Nonuis line, while the left saw only the lower. All other features of the test are seen binocularly. The subject was instructed to fixate on the "XOX" (the central fusion lock). The surrounding text plays the role of a peripheral fusion lock. The subject was asked if the Nonius lines are parallel to

each other or if they are slipped. If there was no slip, the FD was considered zero PD. If the lines were slipped one according to the other, a prism bar with the smallest prism (1 PD) was placed in front of the right eye. The subject was asked if the Nonius lines are parallel to each other or if they are slipped. If there was no slip, the FD was considered 1 PD. If the lines were slipped from one according to the other, a compensating prism increased in step size according to the prism bar and placed before the right eye. The procedure was repeated until the lines slipped in the opposite direction. In that position, the previous prism amount was considered to be associated phoria. The FD value was the highest prism that provided a parallel Nonuis line one with the other. In ta case when with a lower prism, there was crossed slip, and with a higher prism uncrossed slip, the FD value was considered with a middle prism amount. For example, if with 12 BI there was a crossed slip of the Nonius lines and with 14 BI there was an uncrossed slip (showing an eso deviation), the FD was recorded to be 13 BI.

The Fixation Disparity test assesses the binocular vision with no total dissociation. Since this test is done under binocular conditions, it enables the evaluation of the binocularity of the patient under binocular conditions. Mallett unit is a common test used to measure the associated heterophoria. This helps to reveal the degree of decompensation of heterophoria. In their study, Jenkins et al. (1989) tried to find criteria for decompensation in binocular vision using the Mallett Unit. Although this study is of a limited number of patients, it shows that no particular value of heterophoria measured with the Mallett Unit was found that could discriminate between asymptomatic and symptomatic patients. However, using associated heterophoria in this differentiation should be considered one of the criteria for differentiating between compensated, decompensating and decompensated heterophoria.

3.3 Near Point of Convergence (NPC)

The ability to converge eyes is most often assessed by measuring the nearest point where the convergence response can be maintained whilst fixating a smoothly accommodative target approaching the bridge of the nose (Rae, 2015). This point referred to NPC. There are two options to determine the NPC endpoint: objective and subjective. The objective is when the examiner first observes a deviation of the subject's eye drifts outwards. The subjective is the first point where the subject reports diplopia. In this research, NPC was evaluated objectively. Raf-Rule was

used to evaluate the NPC. The fixation target was an optotype two lines larger than the participant's near VA. The examiner smoothly moved the target towards the subject's bridge of the nose at eye-level height. When a deviation of one eye was observed for the first time, while the subject was encouraged to maintain a single target, the distance from this point to the lateral canthus was measured in cm. and recorded to be NPC.

3.4 Vergence Facility (VF)

The subjects were instructed to fixate on a text on a stick held at a distance of 40 cm and to keep the target sharp and single with each rotation of the prism flipper. A 12BO/3BI prismatic flipper was used (one side of the flipper contained 6BO in each cell and the other side 1,5 BI in each sell). This prism amount was recommended by Gall, Wick and Bedell (1998) 12 BO was placed before the eyes while the subject was fully corrected under the binocular viewing condition. The subject was instructed to tell immediately if the target was sharp and single or blurry and double. If it was sharp and single, the optometrist rotated the flipper so that the 3BI prism was in front of his eyes. The flipper was not rotated if the subject reported the doubled or blurred target. Five seconds were given to the participant to achieve sharp and single vision. VF is defined as the number of cycles in which a subject can regain binocular single and clear vision when switching between BO and BI prism demands during a 1-minute trial. The VF measurement unit is cycles per minute (CPM) Askarizadeh et al. (2022).

3.5 Stereopsis

The order of the stereotest examination was a "pseudo-random" process. All the stereoacuity measurements using all of the tests were performed under the next conditions: the participant was using their best correction if it complies with the best optical correction or a trial frame was used, the participant was instructed to hold the test plates at 40 cm., and a 45-degree angle to the facial plane of the participant, and the examiner still was holding the stereotest to make sure that booklet is still at 40 cm away from the participant.

The participant was instructed to hold the test plates at 40 cm. and a 45-degree angle to the participant's facial plane. The examiner held the stereotest to ensure that the booklet was still 40 cm. from the participant. After each measurement, a two-minute break took place.

3.5.1 The Frisby test

The test rested on the edge of the fold-down flap attached to the box, and the top edge was held a few cm. above the flap while keeping the plate square to the participant's line of vision. The edge of the plate was lifted from the background by a few cm. Each plate has four squares, and only one square has a stereo target, seen as a floating circle. The participant was asked to identify the square with the floating or forward from the other circle. The first stereoacuity measurement was done on the 6 mm plate. If the participant successfully discriminated the target in depth, the 6 mm plate was replaced by the 3 mm plate, and the stereoacuity measurement was repeated. If the participant successfully discriminated the target in depth, the 3 mm plate was replaced by the 1.5 mm plate, and the stereoacuity measurement was repeated. After one correct response was observed, the plate was changed to a thinner one. The plates were presented three times, each with a target position varied randomly, starting with the thickest plate at a 40 cm distance. The lowest disparity which the participant could reliably discriminate was recorded. The test provides an option to measure stereoacuity with the next steps: 600, 340, 300, 215, 170, 150, 110, 85, 75, 55, 40, 30, 25, 20, 10, and 5 SOA. The participants were given 15 seconds to answer. The participants were given 15 seconds to answer. If a participant could not recognise the lowest target on the stereotest (showed no global stereoacuity), stereoacuity of 1000 SOA was recorded.

3.5.2 Titmus

The participant wore the polarised filters over his optical correction if needed; the booklet was open and folded so that only Page 2 could be viewed by the subject. The participant was asked to identify which ring in the Wirt Rings Test looked closer or floated towards him in each row starting from the top left ("Which ring looks closer or floats towards you in each row starting from the top left"). The lowest disparity the subject could detect was recorded as his/her stereoacuity in seconds of arc. The test

provides an option to measure stereoacuity with the next steps: 800, 400, 200, 140, 100, 80, 60, 50 and 40 SOA. The participants were given 15 seconds to answer. If a participant could not recognise the lowest target on the stereotest (showed no global stereoacuity), a stereoacuity of 1000 SOA was recorded.

3.5.3 The Randot LEA Symbols Stereoacuity Test

The participant wore polarised filters over his optical correction if needed; the booklet was open so that only Page 2 could be viewed by the subject. The participant was asked to look at the 12 boxes containing three circles and was told that only one circle appeared floating or forward from the others. The participant was asked to identify which circle appears floating or different from the others starting with box #1 ("which circle appears floating or different from the others left, middle or right, starting with box #1). If the participant successfully coped with the last task, the same was repeated for boxes 2-12. The lowest disparity the subject could detect was recorded as his/her stereoacuity in seconds of arc. The lowest disparity the subject could detect was recorded as his/her stereoacuity in seconds of arc. The test provides an option to measure stereoacuity with the next steps: 400, 200, 160, 100, 63, 50, 40, 32, 25, 20, 16 and 12,5 SOA. The participants were given 15 seconds to answer. If a participant could not recognise the lowest target on the stereotest (showed no global stereoacuity), a stereoacuity of 1000 SOA was recorded.

3.5.4 The TNO Stereo test

There are a number of TNO stereotest versions available on the market. The first edition appeared in 1972, and the latest (17th) in 2012. The test is distributed by Lameris Ootech BV and was designed by the Institute For Perception, Netherlands Organisation for Applied Scientific Research. van Doorn et al. (2014) compared the 13th TNO edition with the 15th among one hundred and twenty-one students. The authors found a statistically significant difference between the two editions of the TNO stereotests. They claimed that the test results are not interchangeable. The 19th version provides an option to measure stereoacuity with the next steps: 480, 250, 120 and 60 SOA. The 15th version provides an option to measure stereoacuity with the next steps: 480, 240, 120, 60, 30 and 15 SOA. Since the 15th edition provides a greater range of stereoacuity that can be measured in the present study, the 15th edition was used in this research. In

version 15, there are 3 plates numbered 5, 6 and 7. On plate 5, there are 2 figures for 480 SOA and 2 for 240. On plate 6, there are 2 figures for 120 SOA and 2 for 60. On plate 7, there are 2 figures for 30 SOA and 2 for 15.

The participant wore the Red and Green anaglyphic filters over his optical correction if needed; the booklet was open and folded so that only Plate 5 could be viewed by the test subject. The participant was told that there were four figures of a disc with a sector missing, and he was asked to tell the direction of the missing sector ("What is the direction of the missing sector on the next figures starting from the top left"). If the participant successfully completed the last task, the booklet was opened and folded so that only Plate 6 could be viewed by the test subject. Then, the participant was told that there were four figures of a disc with a sector missing and that he should tell the direction of the missing sector. If the participant successfully coped with the last task, the booklet was open and folded so that only Plate 7 could be viewed by the test subject. The participant was told that there were four figures of a disc with a sector missing, and then he was asked to tell the missing sector's direction again ("What is the direction of the missing sector on the next figures starting from the top left"). The lowest disparity the subject could detect was recorded as his/her stereoacuity in seconds of arc. The participants were given 15 seconds to answer. If a participant could not recognise the lowest target on the stereotest (showed no global stereoacuity), a stereoacuity of 1000 SOA was recorded.

3.6 Fusional Reserves (FR)

The fusional reserves were measured using the prism bar for distance (6 m.) and for near (40 cm.). The prism bar was held at 90 degrees before the participant's right eye, and the prism amount was increased step by step.

On each step, the participant was asked if he/she "noticed" something like discomfort, eye strain, pain, nausea, unusual sensation, etc. If the participant felt nothing, the prism amount was increased. The amount of prism that brought any different feeling was considered as the "Something Point". The word used by the participant to describe the feelings was recorded. The participant was instructed to describe the feeling using only one word, tell the first word that came to mind, and do it as quickly as possible, not allowing prism adaptation. The FR measurement technique

did not differ from the standard. This additional point was called by the author the " Something Point".

After a 30-second break, the FR was measured the standard way.

The prism amount was increased to the next step, and the participant was asked if he/she felt blurriness. If the participant did not feel blurriness, the prism amount was increased in steps of two prism diopters. The amount of prism that brought a blurred vision was considered as the “blur” point. The prism amount was increased to the next step, and the participant was asked if he/she felt double vision. The prism amount was increased if the participant did not feel double vision. The amount of prism that brought a double vision was considered the “break” point. The prism amount was decreased to the previous step, and the participant was asked if he/she felt double vision. If the participant still felt double vision, the prism amount was decreased. The amount of prism that brought back a single vision was considered as the “recovery” point. The test was administered in a manner that approximates a normal FD measurement better, and the patient was oriented to respond as quickly as possible.

On the second and third appointments, FR was measured similarly, but the participant was looking at a stereotest, which served as a target for fixation. Two stereotests served as a target in a randomised order:

- the TNO stereotest 480” target;
- the Titmus stereotest 400” target.

A two-minute break was taken between the measurements.

3.7 Bio-microscopy Protocol

Name_____ **Date**

Table 22: Bio-microscopy Protocol

RE	LE
Eyelids, Eyelashes, Meibomian Glands	
Skin: ☐ normal ☐ hyperaemia ☐ oedema **Ciliary edge:** ☐ clean ☐ other _____ **Meibomian Glands** ☐ open ☐ other _____ **Eyelashes** ☐normal ☐ other _____ **Secretion** ☐ normal ☐ other _____ **Eyelid margin epithelium** ☐ normal ☐ other _____	**Skin:** ☐ normal ☐ hyperaemia ☐ oedema **Ciliary edge:** ☐ clean ☐ other _____ **Meibomian Glands** ☐ open ☐ other _____ **Eyelashes** ☐normal ☐ other _____ **Secretion** ☐ normal ☐ other _____ **Eyelid margin epithelium** ☐ normal ☐ other _____
Conjunctiva	
☐ normal other_____ **Bulbar conjunctiva Hyperaemia of the** ☐1-no ☐2- mild ☐3- moderate ☐4- severe **Staining (fluorescein/ Lissamine green)** ☐1-no ☐2- mild ☐3- moderate ☐4- severe **Limbal Hyperaemia** ☐1-no ☐2- mild ☐3- moderate ☐4- severe **Tarsal conjunctiva Hyperaemia** ☐1-no ☐2- mild ☐3- moderate ☐4- severe **Tarsal conjunctiva Relief** ☐ normal ☐ other _____ **Lid Parallel Conjunctiva Folds** ☐ no ☐ other _____	☐ normal other_____ **Bulbar conjunctiva Hyperaemia of the** ☐1-no ☐2- mild ☐3- moderate ☐4- severe **Staining (fluorescein/ Lissamine green)** ☐1-no ☐2- mild ☐3- moderate ☐4- severe **Limbal Hyperaemia** ☐1-no ☐2- mild ☐3- moderate ☐4- severe **Tarsal conjunctiva Hyperaemia** ☐1-no ☐2- mild ☐3- moderate ☐4- severe **Tarsal conjunctiva Relief** ☐ normal ☐ other _____ **Lid Parallel Conjunctiva Folds** ☐ no ☐ other _____
Tear film	
Tear meniscus height ☐ normal (0,2-0,3 mm) ☐ other _____ **Tear film** ☐ normal (0,2-0,3 mm) ☐ other _____ **TBUT** _____	**Tear meniscus height** ☐ normal (0,2-0,3 mm) ☐ other _____ **Tear film** ☐ normal (0,2-0,3 mm) ☐ other _____ **TBUT** _____
Cornea	
Diameter _____ mm **Overall estimation** ☐ normal (0,2-0,3 mm) ☐ other _____ **Oedema** ☐ no ☐ other _____ **Neovascularization** ☐ no ☐mild <1,5 mm in one quadrant ☐2- moderate <1,5 mm in several quadrants ☐ 3-sever, vascular sprouting 1,5-2,5 mm ☐ 4-critical, > 2 mm **Cornea Fluorescein/Lissamine Staining** ☐ no ☐ other _____	**Diameter** _____ mm **Overall estimation** ☐ normal (0,2-0,3 mm) ☐ other _____ **Oedema** ☐ no ☐ other _____ **Neovascularization** ☐ no ☐mild <1,5 mm in one quadrant ☐2- moderate <1,5 mm in several quadrants ☐ 3-sever, vascular sprouting 1,5-2,5 mm ☐ 4-critical, > 2 mm **Cornea Fluorescein/Lissamine Staining** ☐ no ☐ other _____

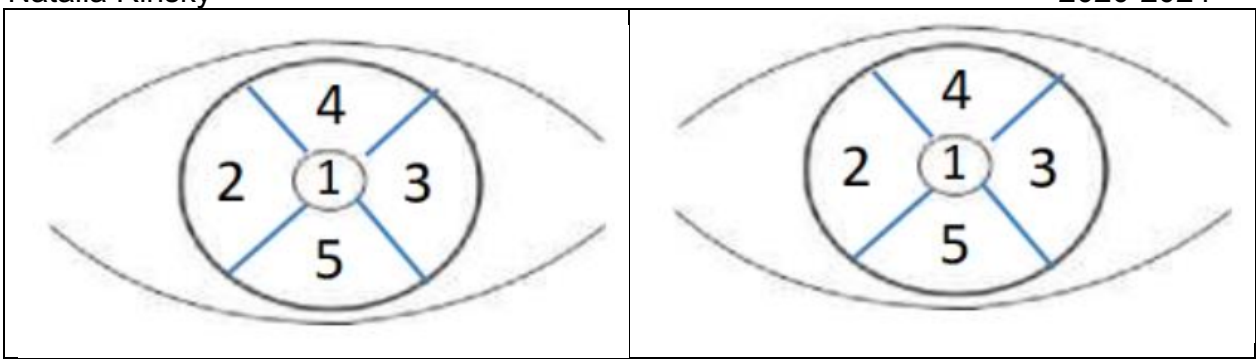


Table 29: Bio-microscopy Protocol.

3.5 Direct Ophthalmoscopy Protocol

Table 30: Direct Ophthalmoscopy Protocol

Direct Ophthalmoscopy Protocol

RE		LE
	media disc margins	
	disc colour	
	C /D	
	vessels	
	A / V	
	SVP	
	macula	
	foveal reflex	
	periphery	
	background	

Table 30: Direct Ophthalmoscopy Protocol.

The protocol sheets

Name_____ Date_____ Participant num. ____
The modified CISS questionnaire result_____

Current correction						
	Sph	**Cyl**	**ax**	**Add**	**VA- D**	**VA- N**
RE						
LE						

Anamneses

Objective Refraction				**Keratometry**					
	Sph	**Cyl**	**ax**			**D**	**at**	**D**	**at**
RE					**RE**				
LE					**LE**				

Entrance Tests					
	Motility	**Pupils reaction**			
		Direct	**Con.**	**Near**	**MG**
RE					
LE					

Subjective Refraction					
	Sph	**Cyl**	**ax**	**VA**	**Binoc. VA**
RE					
LE					

Binocular Vision assessment			
W4Dot			
Schober			
Distance FD			
Distance Vergence Facility (using flipper 12BO/3BI the fixation target was an optotype two lines larger than the participant's near VA in the poorer-seeing eye)			
Distance CT (using prism-bar, the fixation target was an optotype two)			
Near CT (using prism-bar, the fixation target was an optotype two)			
Near FD (using Mallett Unit Tianle NV-100)			
Near Vergence Facility (using flipper 12BO/3BI the fixation target was an optotype two lines larger than the participant's near VA in the poorer-seeing eye)			
AA (using RAF rule, with a fixation target an optotype two lines larger than the participant's near VA)		**RE**	**LE**
NRA/PRA			
Frisby/ Titmus/ Randot /TNO/TNO Trombone (from 80 cm)			
NPC (the fixation target was an optotype two lines larger than the participant's near VA in the poorer-seeing eye)			

Fusional Reserves		
Something (the patient's word) The feeling _____ (FR after 30 seconds)		
blur	**breaking**	**recovery**

Table 31: *The protocol sheet*.

Appendix 4

Excluded 1000 SOA

4.1 Introduction

Stereoacuity was measured using Frisby, Titmus, Randot, and TNO as the baseline. If the participant demonstrated some stereoacuity on one test and no stereoacuity on the other, a value of 1000 SOA was recorded on the tests where the participant failed to pass. Three participants failed in this category. To ensure that the data and conclusions were not affected by the artificial stereoacuity, those three participants were excluded, and the statistics were done once again.

4.2 Methodology

Three participants who had no stereoacuity on one of the tests were excluded.

4.3 Results

The data from the "The Relieving Prism Prescribing, According to Sheard's versus the SPC" experiment (Chapter 4) was reanalysed after three participants were excluded (66 participants were analysed).

4.3.1 The Relieving Prism

The mean relieving prism calculated according to Sheard's Criterion (7.3, ±3.8 PD) was significantly lower than calculated with SPC (12.9, ±5.1 PD) (Figure 33). The Related Samples Wilcoxon Signed Ranked test showed a statistically significant difference with a very low p-value (N=66, Statistic=6.912, $p<0.001$).

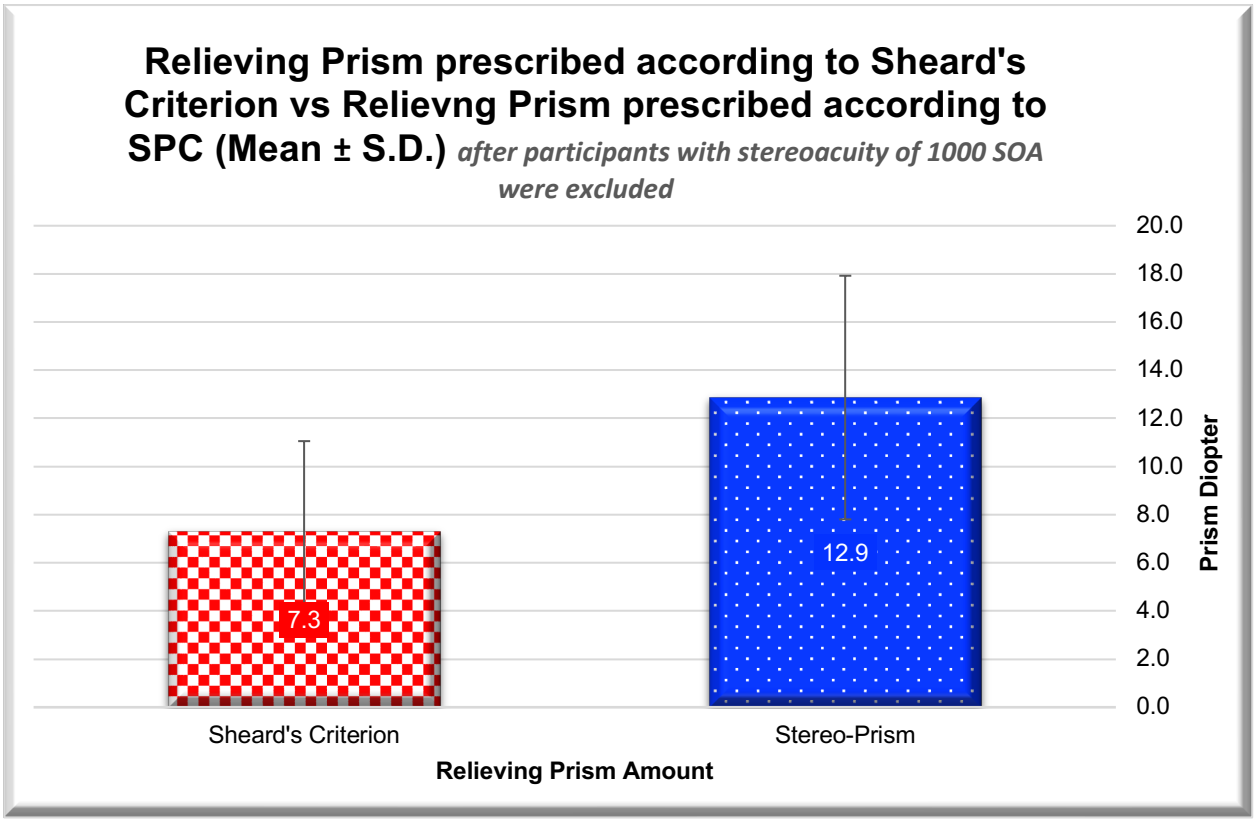


Figure 33: *The graph shows that the mean relieving prism prescribed according to Sheard's Criterion was 7.3, ±3.8 PD and, according to the SPC, 12.9, ±5.1 PD which is significantly higher (p<0.05). The error bars represent the Standard Deviation of the mean.*

4.3.2 The mean modified CISS

The mean modified CISS questionnaire at the baseline was 41.82, with a standard deviation of 6.94. Sheard's Criterion contributed to a higher modified CISS questionnaire mean of 29.76 with a standard deviation of 5.82, and the SPC contributed to an even higher mean of 21.92 with a standard deviation of 6.49 (Figure 34). A comparison between the questionnaire's means was performed using the Repeated Measures ANOVA test. ANOVA showed a statistically significant difference with a very low p-value ($p<0.001$). The value of the test statistics is $F=160.156$ with a degree of freedom 2. A Tukey post-hoc test was performed to determine the significant difference between each test. The Tukey test showed a significant difference ($p<0.001$) between each measured questionnaire means.

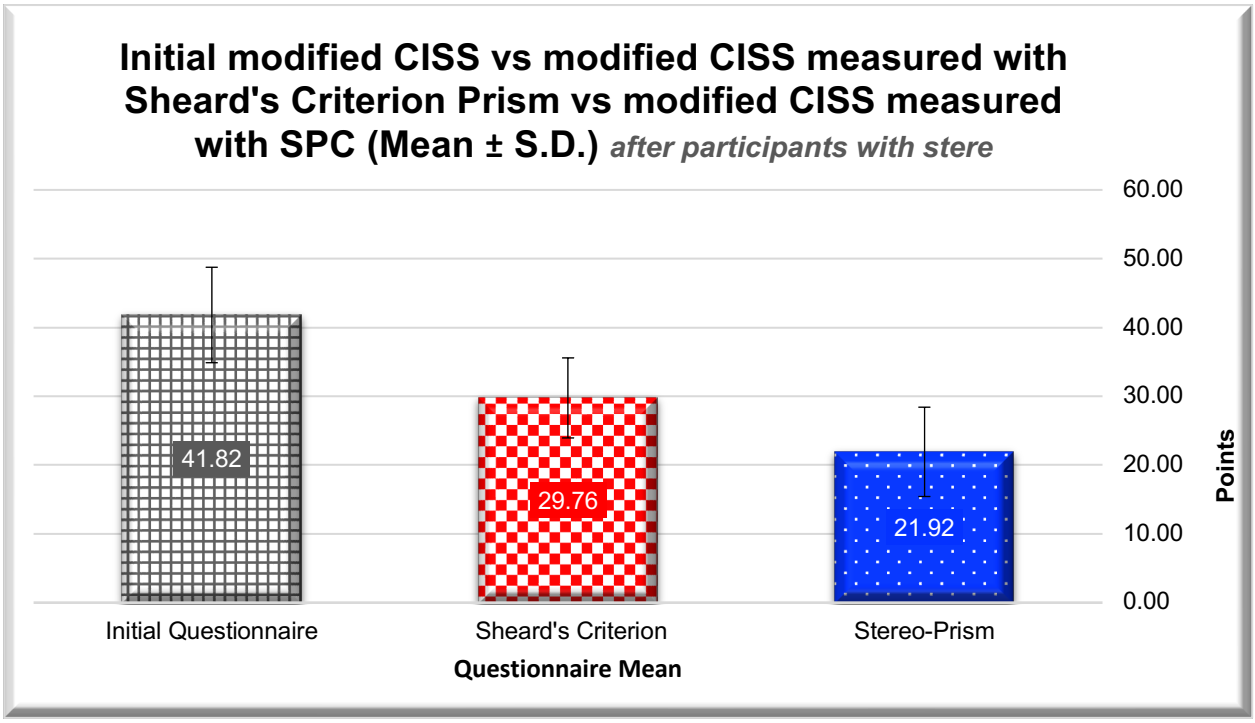


Figure 34: *The graph shows that the reduction of symptoms by the modified CISS questionnaire was greater with the SPC (21.92, ±6.49) than with Sheard's Criterion (29.76, ±5.82) ($p<0.05$). Both criteria contributed to lower symptoms than the baseline level (41.82, ±6.94). The difference was statistically significant after participants with a stereoacuity of 1000 SOA were excluded ($p<0.05$). The error bars represent the Standard Deviation of the mean.*

4.3.3 Stereoacuity

Stereoacuity was measured at the baseline, and after the prism correction was prescribed according to Sheards' and the SPC. Table 32 demonstrates these measurement means.

Table 32: Stereoacuity mean ± S.D. measured with TNO and Titmus stereotests with no prism correction, with relieving prism prescribed according to Sheard's Criterion and with prism according to the SPC after participants with a stereoacuity of 1000 SOA were excluded				
Stereoacuity measurement conditions	Titmus		TNO	
	Mean	SD	Mean	SD
Stereoacuity with no prism correction	202.4	152.7	371.8*	144.8
Stereoacuity with relieving prism prescribed according to Sheard's Criterion	55.3	17.3	102.2*	72.5
Mean modified CISS questionnaire with prism prescribed according to the SPC	43.0	6.6	43.9*	25.8

Table 32: *Stereoacuity mean ± S.D. measured with TNO and Titmus stereotests with no prism correction, with relieving prism prescribed according to Sheard's Criterion and according to the* SPC*. Stereoacuity was evaluated in the Second of Arc. * means that there was a statistically significant difference*

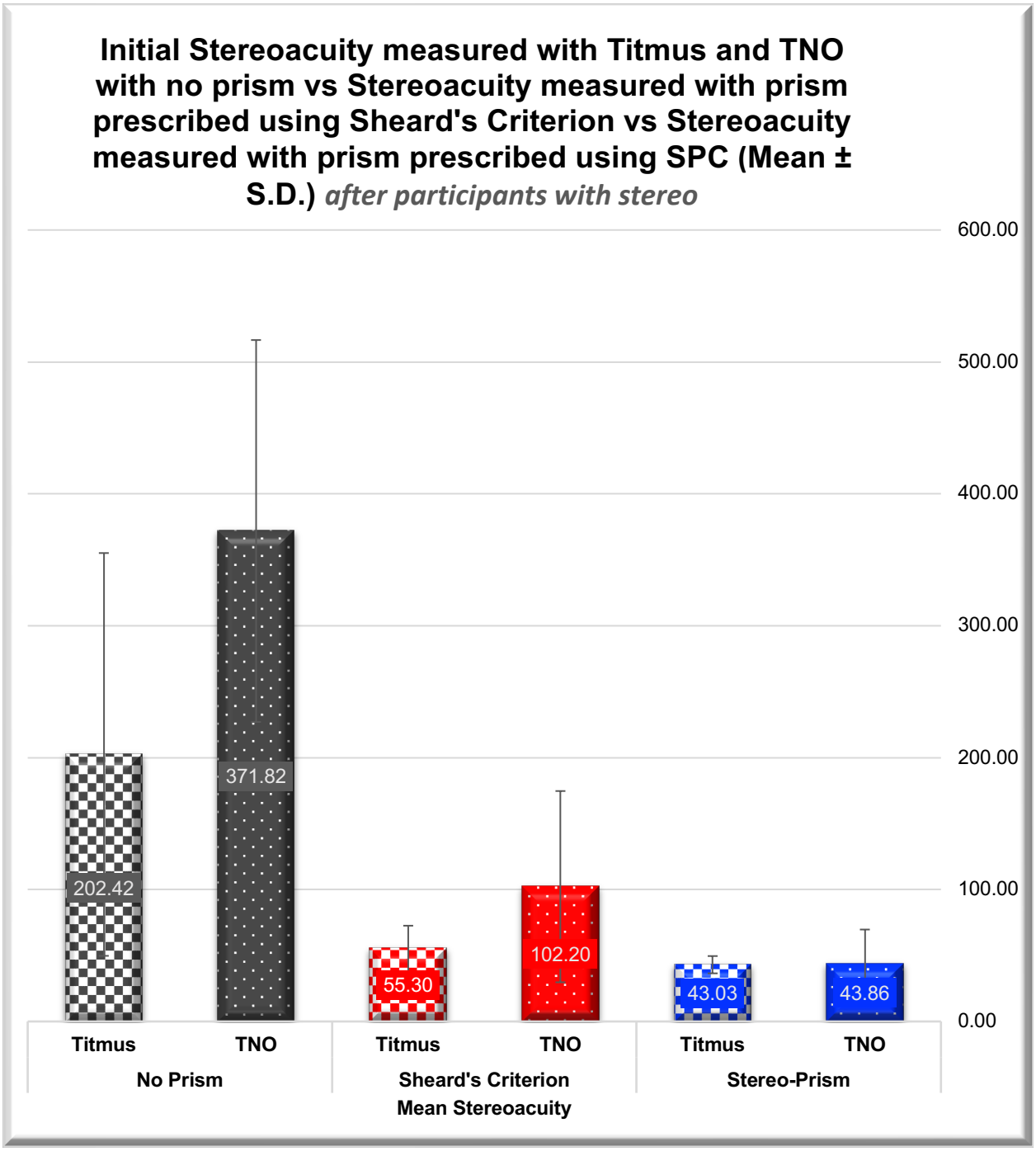


Figure 35: *The graph shows that stereoacuity with no prism (Titmus 202.42, SOA 152.68 SOA; TNO 317.82, ±144.77 SOA) was lower than with the prism prescribed according to Sheard's Criterion (Titmus 55.3.42, ±17.3 SOA; TNO 102.2, ±72.49 SOA) (p<0.05). The prism prescribed according to the* SPC *(Titmus 43.03, ±6.56 SOA; TNO 43.86, ±5.84 SOA) contributed to a higher stereoacuity on both stereotests in comparison to Sheard's Criterion prism (p<0.05). The error bars represent the Standard Deviation of the mean.*

Figure 35 represents the Titmus and TNO test distribution with no prism, and with

each prismatic correction was prescribed. With an increase in the prismatic component, stereoscopic vision improved. The Related Samples Wilcoxon Signed Ranked test was used to compare the data. The test results are represented in Table 33.

Table 33: Stereoacuity mean measured with TNO and Titmus stereotests with no prism correction, with relieving prism prescribed according to Sheard's Criterion and with prism according to the SPC comparison using Wilcoxon Signed Rank test after participants with a stereoacuity of 1000 SOA were excluded

Stereotest and measurement condition	Stereotest and measurement condition	Statistic	p	Outcome
Baseline Titmus	Baseline TNO	6.400	<0.001	The difference is statistically significant
Baseline Titmus	Titmus with Sheard's	-7.167	<0.001	The difference is statistically significant
Baseline Titmus	TNO with Sheard's	-5.197	<0.001	The difference is statistically significant
Baseline Titmus	Titmus with SPC	-7.178	<0.001	The difference is statistically significant
Baseline Titmus	TNO with SPC	-6.884	<0.001	The difference is statistically significant
Baseline TNO	Titmus with Sheard's	-7.082	<0.001	The difference is statistically significant
Baseline TNO	TNO with Sheard's	-6.877	<0.001	The difference is statistically significant
Baseline TNO	Titmus with SPC	-7.201	<0.001	The difference is statistically significant
Baseline TNO	TNO with SPC	-7.039	<0.001	The difference is statistically significant
Titmus with Sheard's	TNO with Sheard's	6.221	<0.001	The difference is statistically significant
Titmus with Sheard's	Titmus with SPC	-5.266	<0.001	The difference is statistically significant
Titmus with	TNO with SPC	-3.922	<0.001	The difference is statistically

Sheard's				significant
TNO with Sheard's	Titmus with SPC	-6.693	<0.001	The difference is statistically significant
TNO with Sheard's	TNO with SPC	-6.188	<0.001	The difference is statistically significant
Titmus with SPC	TNO with SPC	-0.726	0.468	The difference is statistically significant

Table 33: *The mean stereoacuity was significantly different with ether test and both stereotests except for Titmus with SPC vs TNO with SPC.*

4.4 Discussion

Since a limited stereo test diapason, three participants were excluded from the “The Relieving Prism Prescribing, According to Sheard’s versus the SPC” experiment described in Chapter 4 and the data were reanalysed. Excluding participants with a stereoacuity of 1000 SOA showed that according to Sheard’s criteria, the prism was significantly lower than with the SPC. SPC prism contributed to a significant symptom relief compared to Sheard’s Criterion prism measured with a modified CISS questionnaire. The SPC contributed to a higher stereoacuity than Sheard’s, and Sheard’s was higher than stereoacuity at the baseline.

4.5 Conclusion

Excluding the participants with a stereoacuity of 1000 SOA provided the same results as in the “The Relieving Prism Prescribing, According to Sheard’s versus the SPC” experiment (Chapter 4). No major differences in the outcome were found.

Appendix 5

Correlation between Relieving Prisms and Symptoms Level

6.1 Introduction

A correlation between the relieving prism amount gained with Sheard's and SPC and according to the FD method and the modified CISS questionnaires gained after the participants used the prismatic correction was done. This chapter is in the Appendix because the authors recognise that the experiments were not set up to do that, and they are manipulating the data and trying to answer questions. The experiments were not set to answer those questions. The correlation tried to answer the question of whether the SPC had a higher correlation than the other two prism prescribing methods or not. The higher the correlation, the more individual the results are than the group mean. If the correlation is relatively high, it means that each individual's prism relates well to the relief of symptoms.

The higher the correlation, the finer the tune to the individual. The higher the correlation, the higher the symptom relief with a given prism for each individual. The higher the correlation, the more applicable the criterion to the individual.

6.2 Methodology

A correlation was made between the relieving prism amount prescribed according to Sheard's criterion, SPC, versus the modified CISS questionnaire at the baseline and after each period of prismatic correction among the first cohort of participants (Chapter 4).

A correlation was made between the relieving prism amount prescribed according to the FD method, SPC, versus the modified CISS questionnaire at the

baseline and after each period of prismatic correction among the second cohort of participants (Chapter 5).

2.3 Results

Figure 36 illustrates no significant correlation between the relieving prism amount prescribed according to Sheard's criterion and the modified CISS questionnaire taken at the baseline (Spearman's correlation *N*=69; Spearman's correlation=0.082, *p*=0.505) and gained after the participants used a prismatic correction prescribed according to Sheard's criterion (Spearman's correlation *N*=69; Spearman's correlation = 0.003, *p* = 0.981) (Chapter 4).

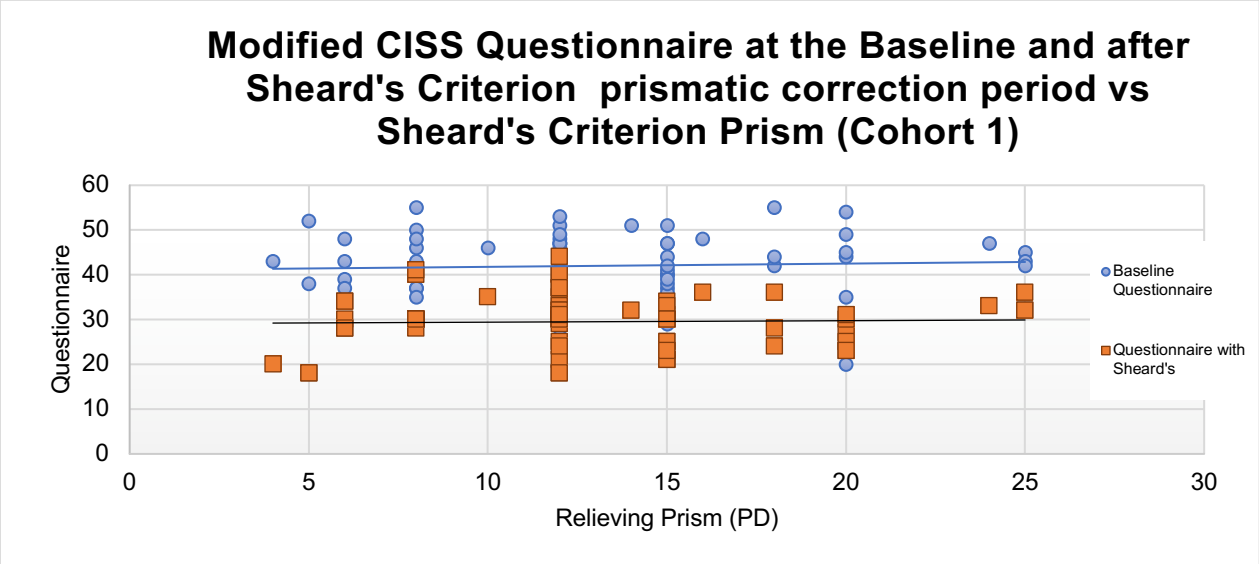


Figure 36: There was no significant correlation between Sheard's Criterion prism and the level of symptoms at the baseline (p=0.505) as well as after the period of prismatic correction (p=0.981) among cohort 1.

Figure 37 illustrates no significant correlation between the relieving prism amount prescribed according to SPC and the modified CISS questionnaire taken at the baseline (Spearman's correlation *N*=69; Spearman's correlation=0.082, *p*=0.670) and gained after the participants used a prismatic correction prescribed according to SPC (Spearman's correlation *N*=69; Spearman's correlation=0.203, *p*=0.058) (Chapter 4).

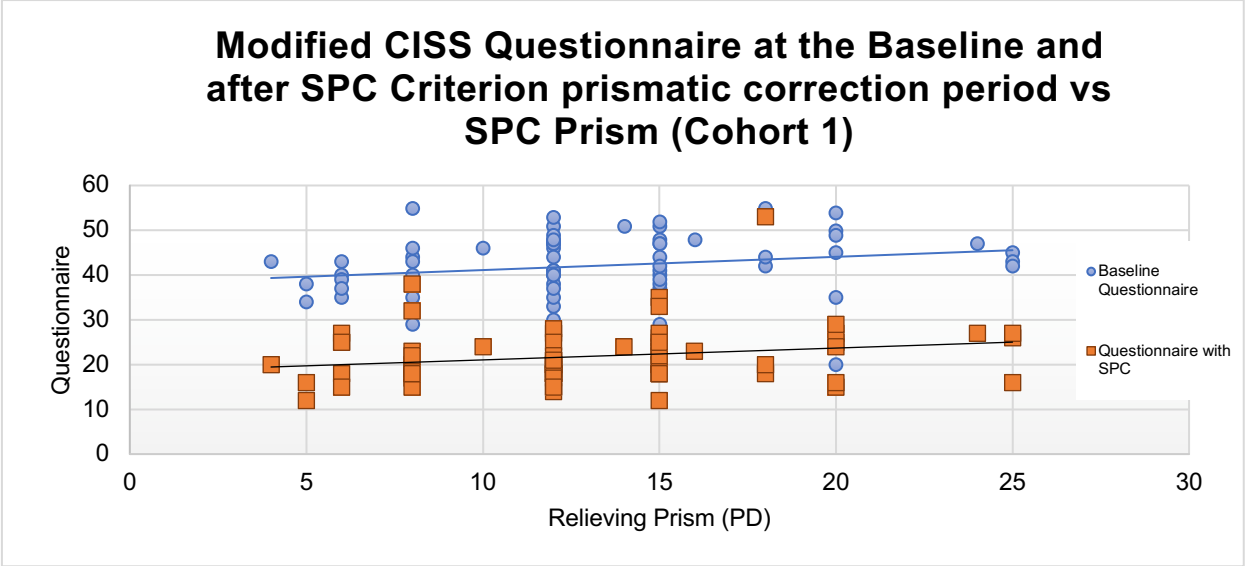


Figure 37: There was no significant correlation between SPC prism and the level of symptoms at the baseline (p=0.670) as well as after the period of prismatic correction (p=0.058) among cohort 1.

Figure 38 illustrates no significant correlation between the relieving prism amount prescribed according to the FD method and the modified CISS questionnaire taken at the baseline (Spearman's correlation *N*=51; Spearman's correlation=0.086, *p*=0.550) and gained after the participants used a prismatic correction prescribed according to FD method (Spearman's correlation *N*=51; Spearman's correlation=0.20, *p*=0.889) (Chapter 5).

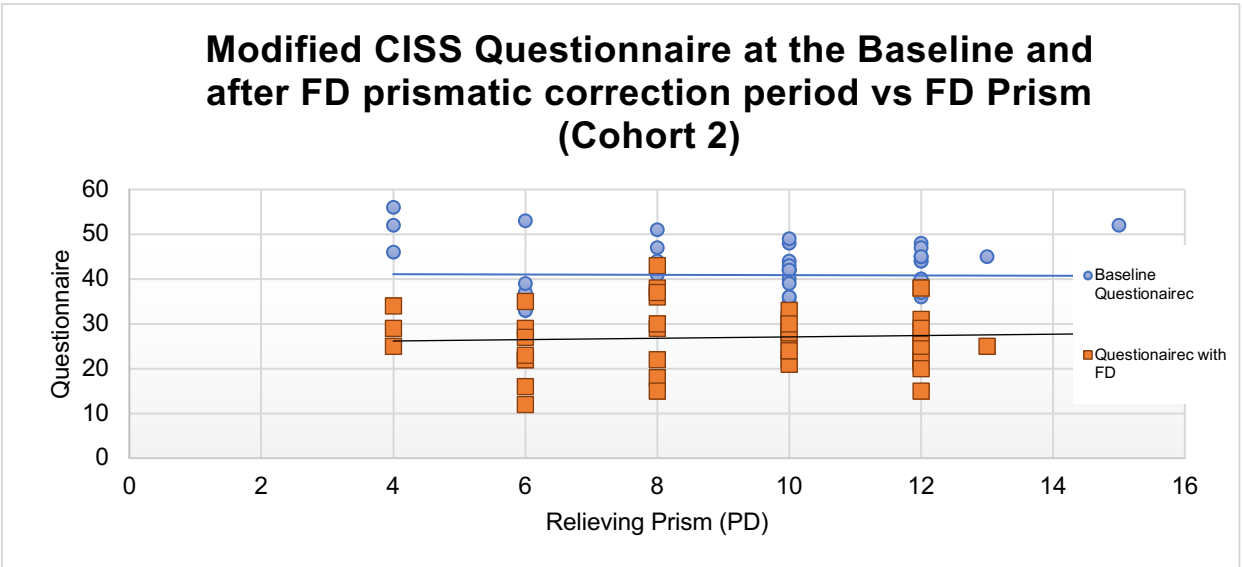


Figure 38: There was no significant correlation between FD prism and the level of symptoms at the baseline (p=0.550) as well as after the period of prismatic correction (p=0.889) among cohort 2.

Figure 39 illustrates no significant correlation between the relieving prism amount prescribed according to SPC method and the modified CISS questionnaire taken at the baseline (Spearman's correlation *N*=51; Spearman's correlation=0.094, *p*=0.511) and gained after the participants used a prismatic correction prescribed according to SPC (Spearman's correlation *N*=51; Spearman's correlation=0.56, *p*=0.696) (Chapter 5).

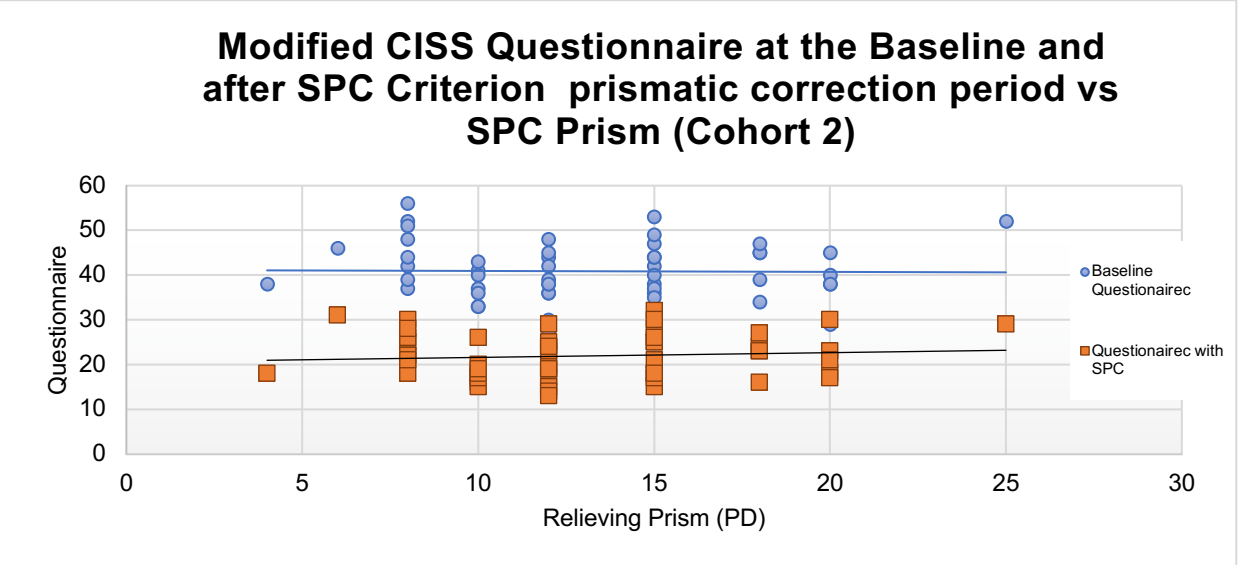


Figure 39: There was no significant correlation between SPC prism and the level of symptoms at the baseline (p=0.511) as well as after the period of prismatic correction (p=0.696) among cohort 2 (Chapter 5).

3.4 Discussion

The relieving prism found no correlation with each method. Because the statistical significance was not reached, it cannot be concluded that the SPC correlates better with the symptoms than the other two prism prescribing methods.

Bade et al. (2013) found no association between the level of symptoms among symptomatic children with CI and the severity of ocular signs. The authors found that the exophoria, PFV, Sheard phoria/ vergence relationship, or NPC findings were not significantly different between subjects with mild, moderate or severe binocular vision

tests and the CISS scores. Moreover, the authors stated that a higher level of subject symptoms did not increase as the clinical signs were more severe. Clark and Robert (2015) demonstrated that CISS scores significantly overestimated near visual symptoms among children with normal binocular vision while reading with symptoms caused by preferred near activities. Both near-vision activities required similar convergence and amplitudes of accommodation from the subject. However, the reading process seems to cause more symptoms than preferred visual activities. Horwood et al. (2014) claimed that CISS could not be used as a screening tool to differentiate symptomatic CI because of a high false positive rate and poor sensitivity. The study demonstrated that most subjects that have clinical signs of CI, such as reduced fusion range and convergence, are asymptomatic. On the other hand, Rouse (2004) stated that symptomatic adults with CI had a significantly higher CISS score than those with normal binocular vision. The author claimed that CISS is a valid and reliable instrument for measuring the outcome of research studies of adult subjects with CI.

The symptoms show no relation to the amount of relieving prism. The level of symptoms may not serve as an indicator of the degree of phoria decompensation and the amount of relieving prism required. This means that the practitioner must rely on objective measurements rather than the patient's subjective opinion expressed in the questionnaire.

There was a connection between the relieving prism and symptoms (Chapters 4, 5); the prism contributed to significant symptom relief. With SPC, symptoms are reduced to a virtually normal level, yet there was no correlation between the degree of symptoms either on the baseline or after the participants were using a prismatic correction and the size of the relieving prism. This means the symptoms reported by the patient do not relate to the degree of decompensation. This lack of correlation presents an exciting opportunity for further exploration in future work.

Neither the initial symptom level nor the final level was found to correlate with the relieving prism amount. Therefore, the change did not correlate well with the actual amount of the relieving prism required. It suggests that the participants are symptomatic and have complaints as a group, but the individuals did not give a consistent symptom level versus severity correlation. Therefore, the symptoms of decompensating exophoria cannot provide the relieving prism amount needed.

Pang et al. (2012) reported that in their research with twenty-eight adult participants they found no correlation between the severity of symptoms using CISS and clinical measurements (near heterophoria, FD and NPC) before and after prism treatment. This finding are on consistence with the finding of this research.

6.5 Conclusion

The experiments (Chapters 4 and 5) demonstrated that the relieving prism contributes to symptom reduction. However, the opinion of subjects regarding their symptom has no correlation with the level of phoria decompensation and no correlation with the treatment required. The modified CISS may be used as a screening tool but not as a diagnostic tool. Therefore, the practitioner has to rely on the best methods available, and those methods should be improved in future work.

Appendix 6

Vision Therapy

Each subject had a VT treatment programme tailored to the presenting signs and symptoms at the beginning of the VT. The Follow-Up examination was done after the 12th in-office session. Prior to each treatment session, written instructions for each device, including with what load it should be carried out and the number of minutes it should be administered, were provided to the orthoptist. The load on the visual system gradually increases. The VT treatment programme was reviewed based on the participant's progress every three in-office sessions and upon the follow-up examination. The treatment programme consisted of three phases (Table 34). With the increase of fusion reserves, a deviation angle decrease and FD, improvement and other functions of the binocular system improvement, and improvement of global stereoscopic vision, the relieving prism gradually decreased.

The VT treatment Phases		
Phase 1	**Phase 2**	**Phase 3**
Voluntary convergence	NFR amplitude	Convergence/divergence demand change
Visual feedback awareness	NFR facility	Vergence procedures and accommodation integration
PFV amplitude	PFV Facility	Versions
AA		Saccades
Accommodation relaxation		

Table 34: *The VT treatment Phases (Scheiman M. & Wick, 2002, Chapter 3, page 236).*

Each lesson had a combination of devices, with the help of which the load was carried out.

Work with each device began with the prismatic value that the patient could cope with, but he needed to apply a fusion load to manage it. Gradually, the vergence

demand increased. One divergence load was given for every 3-5 convergence loads, and vice versa. An additional vergence and accommodative load was achieved using prismatic and dioptric flippers.

The following equipment was applied in the in-office sessions:

- **Anaglyphs and Tranaglyphs;**

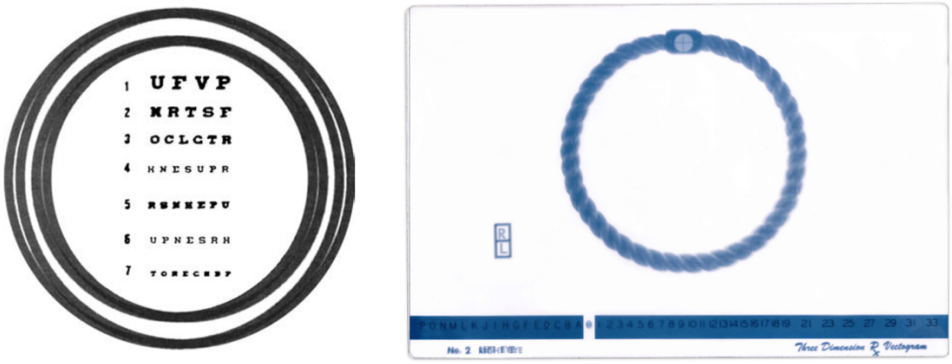
Anaglyphs and Tranaglyphs filters block light from part of the target elements being viewed. With the filter, part of the elements can be seen only by the right eye, part by the left eye, and part is viewed binocularly. The technique was used to work on fusion, anti-suppression, stereopsis, fusional reserves' amplitudes and facilities, and combining the vergence load with accommodation using flippers. Moreover, additional targets were used for pursuit and saccadic training. The fusional range was up to 30 prism diopter BI and BO. Picture 5 demonstrates examples of Anaglyphs and Tranaglyphs targets.

Picture 5: *Anaglyphs (to the left) and Tranaglyphs (in the middle and to the right) targets*.

- **Vectograms;**

Vectogram enables free voluntary vergence. Visual feedback awareness was achieved using the "small in, large out" phenomenon. This illusion brought the binocular system to perceive a target to become smaller and closer while convergence occurred and bigger and farther away while divergence occurred (Leibowitz, Shiina &Hennessy, 1972; Leibowitz & Moore, 1966). A vectogram was used to work on fusion, anti-suppression, stereopsis, 21the fusional reserves amplitude and facilities combined with

accommodation demand (using flippers). Targets with and without peripheral and central fusion (locks) were used, and other targets enabled hand-eye coordination, pursuit and saccadic training. The fusional range was up to 30 prism diopter BI and BO. Picture 6 demonstrates examples of Vectogram targets.



Picture 6: *Vectogram targets*.

- **Prismatic and accommodative flippers;**

Plus/minus flippers for accommodation demand and prism flippers for vergence demand were used in conjunction with anaglyphs, tranaglyphs, vectograms, aperture rule, etc. The main application was for vergence and accommodation facility training. The plus/minus lens powers range was 0.25, 0.50, 1.00, 1.50, 2.00, and 2.50 diopters. A set of 24 pairs ranging from 0.25PD to 10PD was used for prismatic flippers. Picture 7 demonstrates the flipper sets.

Picture 7: *Plus/minus lens flippers (to the left) and prism flipper sets (to the right).*

- **Bernell'o Scope;**

Bernell'o Scope was used to allow work on binocular stability, vergence amplitude and facility, FD, fusion, anti-suppression, and stereopsis. The patient was looking through the device's eyepieces (with +5.00D lenses) at the target. A wide range of targets were used with different fusion/vergence demands. The cards' vergence range was zero up to 32 prism diopter Base-Out in 2 prism diopter steps and up to 16 prism diopter Base-In in 2 prism diopter steps. Picture 8 demonstrates the Bernell'o Scope and the targets.

Picture 8: *Bernell'o Scope (to the left) and the targets (to the right).*

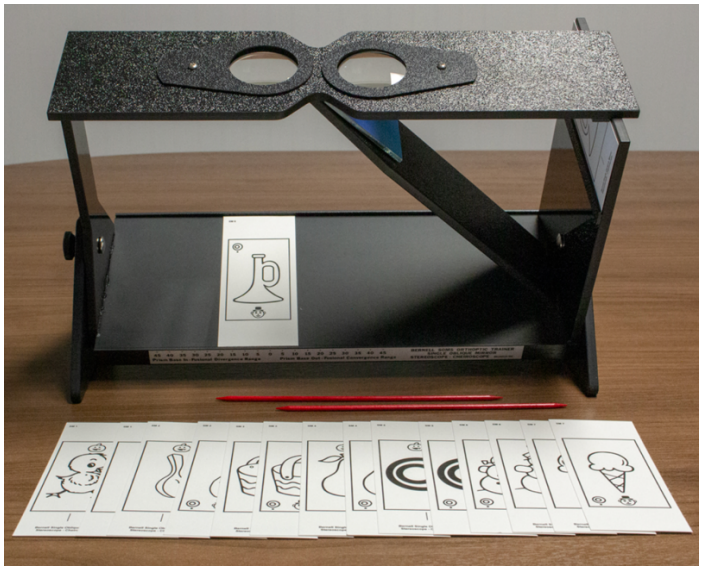
- **Aperture Rule;**

The Aperture Rule was used to improve binocular stability, vergence amplitude and facility, accommodation amplitude and facility, tight accommodation-convergence relationship, FD, fusion, anti-suppression, and stereopsis. The device is generally considered a free space technique. The patient had to position him/herself directly against the device and look into the instrument on the presented targets. A wide range of targets were used with different fusion/vergence demands. The cards' vergence range was zero, up to 30 prism diopter Base-Out in 2 prism diopter steps and up to 17.5 prism diopter Base-In in 2 prism diopter steps. Picture 9 demonstrates the Aperture Rule and the targets.

Picture 9*: Aperture Rule (to the left) and the targets (to the right).*

- **Cheiroscope;**

A Cheiroscope was used to work no fusion, anti-suppression, FD, binocular stability and binocular alignment, and eye-hand coordination. The patient had to position him/herself directly against the device and look through the eyepieces (with +6.00D lenses) of the device at the target. One visual axis went directly to one target (seen by one eye) and the other through the mirror to the second (seen by the other eye). The elements of the paired targets complement each other. Targets of a different type (unpaired targets) were placed on the side of the device (visible through a mirror). Instead of the second target, a clean sheet of paper was placed, and the patient was asked to draw the target that he saw with one eye while looking at what he was drawing with the other. Picture 10 demonstrates the Cheiroscope and the targets.



Picture 10*: Cheiroscope with targets.*

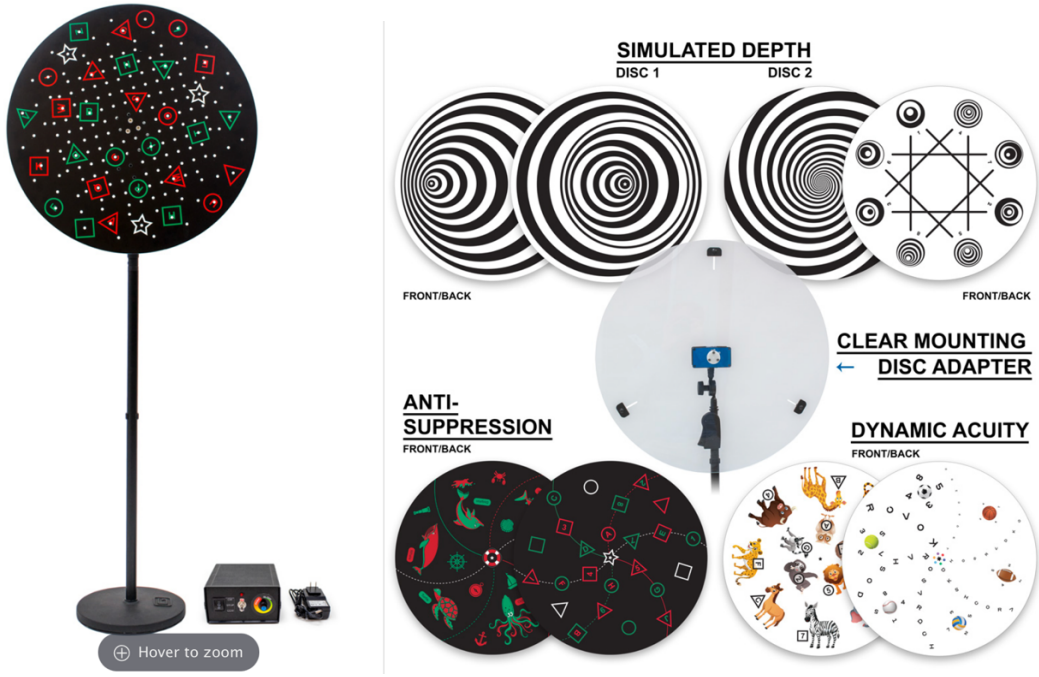
- **Mirror Stereoscope**;

The device was used to work on a free space technique. The patient had to position him/herself directly against the device and look into the instrument on the presented targets. The device had no lenses or prisms; the patient looked at the paired targets through mirrors (one for each visual axis). The Mirror Stereoscope was used to work on binocular stability, vergence amplitude and facility, accommodation amplitude and facility, tight accommodation-convergence relationship, FD, fusion, anti-suppression, and stereopsis. A wide range of targets was used with different fusion/vergence demands. The cards' vergence range was zero, up to 50 prism diopter Base-Out in 2 prism diopter steps and up to 40 prism diopter Base-In in 2 prism diopter steps. Picture 11 demonstrates the Mirror Stereo and the targets.

Picture 11*: Mirror Stereoscope with targets (to the left) and additional targets (to the right).*

- **Rotator**;

This technique improved the accuracy and speed of pursuit, saccadic eye movements, eye-hand coordination, perceptual and space awareness, dynamic visual acuity, and dynamic fusional training. Flippers were used to induce vergence/accommodation demand. There were anaglyphic disc targets and a simple (used with no dissociation filters). The disc was rotated in either direction (clockwise or counterclockwise) and with different rotation speeds. Some rotator discs were pegboards with holes where a golf tee could be placed. Picture 12 demonstrates the Rotator and discs.



Picture 12*:* Rotator *(to the left) and Rotator discs (to the right).*

- **Marsden ball.**

The used Marsden balls were 3.50" in diameter, had different figures, and could be Red/Green (anaglyphic). The balls were suspended from the ceiling, and their height was adjusted according to the patient's height. It was swung from side to side, forward and backwards, or in a circle. The Marsden balls improved the accuracy and speed of pursuit and stereopsis and provided anti-suppression exercises. Flippers were used to induce accommodation and vergence demand. The vergence and stereoscopic demand were in conjunction with the vectogram held in a transparent holder. Picture 13 demonstrates the Marsden balls.

Picture 13*: Marsden balls.*

Please see Scheiman M. & Wick B. (2002) for additional information regarding the VT procedures and techniques. Clinical management of binocular vision. 2nd ed. USA: Lippincott-Raven; pp. 224.

The VT equipment was bought at https://www.bernell.com.

The in-home treatment is carried out using:

The patients received instructions for what they were asked to do at home. Regarding each exercise, detailed written and video instructions were provided on how to perform the exercise, which visual load was used, and for how long. The patients were asked to perform the homework three sessions times a day for 20 minutes long each.

- **Brock String**;

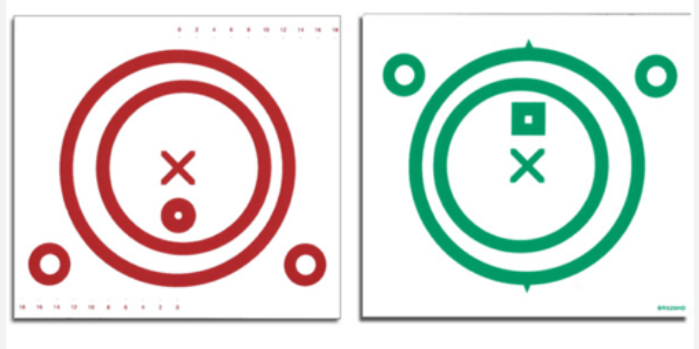
Brock String is a long white cord with three wooden beads of different colours attached. It was used to train physiologic diplopia and kinesthetic awareness of converging and diverging, develop voluntary convergence and divergence ability, and normalise the NPC. Picture 14 demonstrates the Marsden balls.

Picture 14*: Brock String.*

- **Red/Green eccentric circles;**

The Red/Green eccentric circlers were used to increase the positive and negative fusional reserves, decrease the fusional vergence response latency, increase the fusional vergence response's velocity, and increase stereopsis. There were two cards

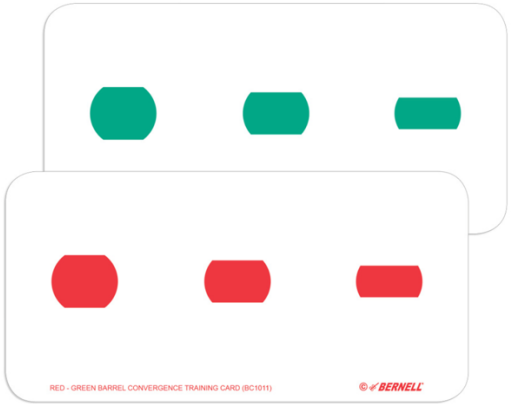
with circles and other target elements printed on them. The circles were shifted uniformly in positions on one and the second card. The separation between the cards increased the vergence demand. Picture 15 demonstrates the Red/Green eccentric circles.



Picture 15*: Red/Green eccentric circles.*

- **Barrel card**;

The Barrel card features three red targets on one side and three green on the other, aligned opposite each other. The Barrel card was used to normalise the near point of convergence. Gazing from one target to the opposite enhanced convergence abilities. Picture 16 demonstrates the Barrel card.

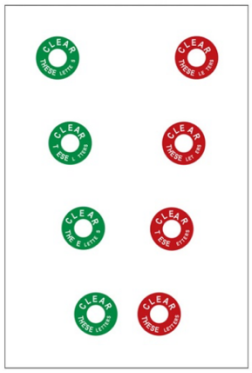


Picture 16*: Barrel card.*

- **Life-Saver card;**

The Life-Saver card is a free space fusion card with four pairs of targets printed at different distances, one from the other. The closer the target is to the other, the lower

the vergence demand. The Life-Saver card increased the positive and negative fusional reserves, decreased the fusional vergence response latency, and increased the fusional vergence response's velocity and stereopsis. Picture 17 demonstrates the Life-Saver card.



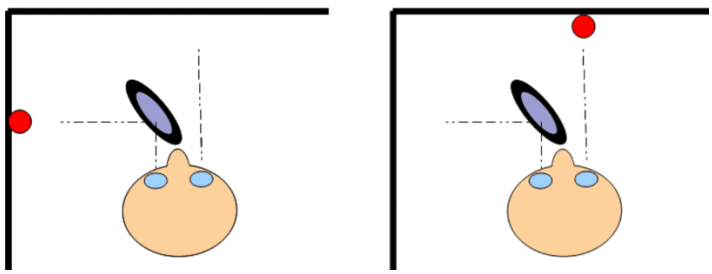
Picture 17*: Life-Saver card.*

- **Pencil Push-up**;

The Pencil Push-up procedure was used to increase the PFR and work on NPC. It required a target (e.g. pencil or pen) to fuse while the patient slowly brought it closer to the nose. The target had to be kept clear and single for as long as possible while the pencil was moved closer to the nose.

- **Physiological diplopia with mirror**;

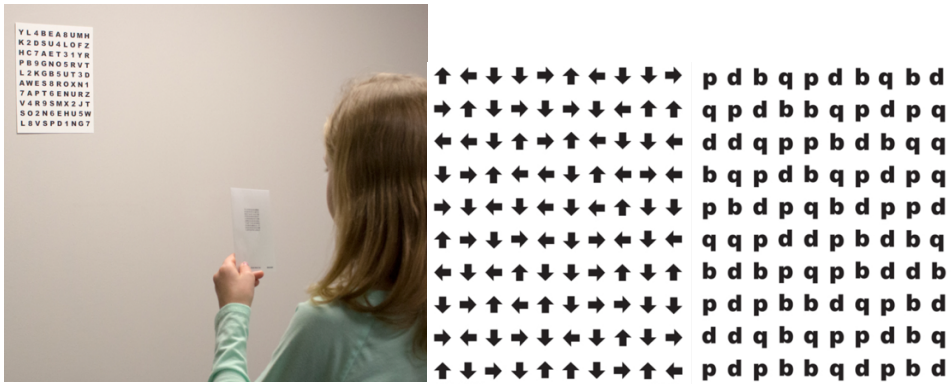
The procedure required two targets: one is on the wall in front of the patient, and the other is on a wall to the patient's left. The patient held a mirror in front of the nose at a 45-degree angle so the right eye could see the target in front, and the target on a wall to the left was seen in the mirror by the left eye (Picture 18) or vice versa. The goal was to fuse the targets. The Physiological diplopia enabled the work of fusion and anti-suppression. The procedure is also called the mirror superimposition.



Picture 18*: Physiological diplopia with mirror.*

- **Accommodation jump**.

The procedure aims to restore normal accommodative amplitude and facilitate range and speed. Two accommodative targets with the same optotypes in the same order were needed. One, with bigger optotypes, was on the wall, and the other, with smaller optotypes, was held by the patient (Picture 19). The distance from the wall and the distance from the eyes to the handheld target changes the accommodation and vergence demand. The patient had to read one optotype from each target in turn. Accommodation demand can be isolated from fusion and vergence by closing one eye. The technique also called Hart chart rock



Picture 19*: Accommodation jump procedure (to the left). Target for Accommodation jump (in the middle and to the right).*