# A COMPARATIVE STUDY OF SUBJECTIVE HETEROPHORIA TESTING WITH A PHOROPTER AND TRIAL FRAME AMONG HEALTH SCIENCE STUDENTS AT UNIVERSITY OF LIMPOPO, SOUTH AFRICA

**By**

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**DISSERTATION**

Submitted in fulfilment of the requirements for the degree of

**MASTER OF OPTOMETRY**

in the

**FACULTY OF HEALTH SCIENCES**

**(School of Health Care Sciences)**

**at the**

**UNIVERSITY OF LIMPOPO**

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**2021**

# DEDICATION

This dissertation is dedicated to my son Tshegofatso Makwela and my daughter Kamogelo Makwela for their unconditional love, support, patience and their encouragement during my study period.

## DECLARATION

I declare that "A COMPARATIVE STUDY OF SUBJECTIVE HETEROPHORIA TESTING WITH A PHOROPTER AND TRIAL FRAME AMONG HEALTH SCIENCE STUDENTS AT UNIVERSITY OF LIMPOPO, SOUTH AFRICA" hereby submitted to the University of Limpopo, for the degree of Master of Optometry has not previously been submitted by me for a degree at this or any other university; that it is my own work in design and in execution, and that all material contained herein has been duly acknowledged.

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**TSOTETSI A.L (MS)** **Date**

## ACKNOWLEDGEMENTS

I would like to convey my sincere gratitude to the following:

My Parents: My late father Mpho Samuel Tsotetsi, my late mom, Morongoenyana Mary Tsotetsi and her late twin sister Morongoe Meriam Moloi, for introducing and encouraging me to follow the intellectual pursuit.

My two children, Tshegofatso Makwela and Kamogelo Makwela for their continuos support and encouragement.

My siblings, Ms Palesa Tsotetsi and Ms Tshepiso Tsotetsi for being my pillars of strength.

My Supervisors, Mr Joas Ramaja and Professor Solani Mathebula, for your guidance, support and encouragement.

Mr Thabelang Mokoena, Mr Thabo Maluleke, Mr Andrew Chikara, Ms Dimakatso Supe and Ms Kamogelo Themane: Thank you very much for your assistance with gathering of the student participants.

Professor Tebogo Mothiba and Ms Irene Melwa, thank you very much for your inspiration and encouragement.

All the people who took part in the study, it was through you that this study was possible.

The University of Limpopo and the Optometry Department for accommodating me as one of their Postgraduate students.

To the Almighty God, for always being by my side throughout my studies and my life.

## ABSTRACT

**Background:** There are several clinical techniques for the subjective measurement of heterophoria. In South Africa, von Graefe is one of the most commonly used techniques to quantify heterophoria using the phoropter. However, most rural community clinics have trial frames rather than phoropters to perform heterophoria measurements and other clinical tests.

Heterophoria or phoria is the misalignment of an eye that occurs when binocular sensory fusion is blocked. The distance heterophoria is determined by the tonic vergence resting state and negative accommodative vergence. In distance vision, normal heterophoria is zero. The tonic vergence resting state is the vergence angle dictated by tonic vergence innervation alone. However, during a near heterophoria test, the vergence angle observed involves multiple innervational factors. Blocking binocular fusion eliminates disparity vergence innervation. Because of the dual interaction, the loss of disparity vergence innervation initiates simultaneous changes of accommodation innervation.

**Purpose:** The purpose of the study was to investigate the agreement of von Graefe heterophoria measurement using the phoropter and a trial frame.

**Setting**: The study was conducted at an Optometry Clinic, University of Limpopo, South Africa.

**Methods:** Distance and near horizontal and vertical heterophoria measurements were performed on 88 visually-normal university students using the phoropter and a trial frame. The 95% limits of agreement were compared using the exact Bland-Altman statistical test.

To measure the horizontal heterophoria, 12 prism base-in was placed before the right eye and 6 prism base-up before the left eye. The prism in front of the right eye was reduced until the participant reported that the two images were vertically aligned. The vertical heterophoria was measured by reducing the prism in front of the left eye until the participant reported that the two images were horizontally aligned. Zero deviation was recorded as ortho or orthophoria.

**Results:** For distance horizontal heterophoria, the Von Graefe values were 0.39±2.0 and 0.38±1.8Δ with the phoropter and trial frame, respectively. The mean near horizontal heterophoria were 3.69±3.3 and 4.13±3.27Δ with the phoropter and trial frame. There were no significant differences between the mean heterophorias measured using the phoropter and the trial frame, $p > 0.05$. For the vertical heterophorias at distance and near vision, the means were close to orthophoria. The mean differences and limits of agreement showed good agreement of Von Graefe test using the phoropter and trial frame.

**Conclusion:** Measurement of Von Graefe testing with the phoropter and trial frame showed a high level of agreement for both distance and near vision performed through the phoropter and a trial frame. For clinical and research purposes, the phoropter and trial frame can be used interchangeably for measuring heterophoria.

**Keywords:** heterophoria, phoropter, trial frame, von Graefe, prism.

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**CHAPTER ONE**

# 1. INTRODUCTION

A normal function of binocular vision includes both the sensory and motor components which guarantee proper alignment of the eyes (Griffin & Grisham, 1995). The sensory component unifies the perception of the images of the two eyes, while the motor fusion component is responsible for aligning the eyes in such a manner that sensory fusion can be maintained. If one eye is artificially excluded from participating in vision (that is if the sensory and motor fusion components of binocular vision are suspended), a relative deviation of the visual axes may appear in most individuals, which is called heterophoria (Casillas & Rosenfield, 2006).

Heterophoria (phoria) is a latent deviation of the eyes and becomes evident only when the normal fusion mechanisms are disrupted (Anstice et al., 2021; Canto-Cerdan et al., 2018; Ficchin & Maffioletti, 2021). The deviation may be horizontal if the visual axis of one eye converges (esophoria) or diverges (exophoria) more than the other, vertical if one visual axis is higher than the other. However, if the fusion mechanism does not function properly, a manifest deviation of one eye is present and is referred to as heterotropia (tropia) or strabismus (Wajuihian, 2018).

Ophthalmic professionals commonly use heterophoria measurements to assess binocular vision in both children and adults. Clinically, heterophoria can be measured by many techniques which use varying stimuli, methods of dissociation and patient instructions. Heterophoria measurement is routinely employed as part of the diagnosis of decompensating binocular vision disorders, and after binocular vision conditions (Schroeder et al., 1996).

A wide variety of techniques are available to the clinician for the subjective measurement of heterophoria. In South Africa and around the world, Von Graefe is the commonly used method for heterophoria measurements and has good repeatability and reliability (Wajuihian 2018). Measurements are done using a phoropter with the target positioned in the midline primary position. However, according to Casillas and Rosenfield (2006), the use of a phoropter during heterophoria measurements may influence the clinical findings.

The Von Graefe method has been used for heterophoria measurements for a number of years and the dissociation is achieved using the vertical prisms (Sanker et al., 2012). This technique enables even the smallest amount of heterophoria to be recorded and the test instructions are easy to understand for participants (Wajuihian 2018). However, the phoropter may influence eye positioning during clinical testing due to differences in head and eye position, proximal vergence and restriction of the peripheral visual field (Casillas & Rosenfield 2006). Testing young children, using the phoropter may be confusing, and as a result making achieving accurate measurements difficult (Lyon et al., 2005).

In South Africa most eye care units in hospitals and in community clinics have trial frames rather than phoropters to measure heterophoria and other binocular tests. The use of a trial frame to measure heterophoria is imperative in such settings. It will allow examiners to directly observe the eyes in a natural setting and easier for subjects to follow instructions (Lyon et al., 2005). It is unknown whether the results produced by trial frame would be identical and/or whether the tests would be interchangeable with the phoropter. Thus, the aim of this study was to compare von Graefe heterophoria measurements using the phoropter and the trial frame.

## 2. AIMS OF THE STUDY

The aim of this study:

i. To compare subjective heterophoria findings using the phoropter and the trial frame among the Health Science students at University of Limpopo.

## 3. OBJECTIVES OF THE STUDY

The objectives of the study:

i. To measure the subjective heterophoria at distance and near using the phoropter and trial frame among the Health Science students at the University of Limpopo.

ii. To compare the distance and near subjective heterophoria results obtained using the phoropter to those obtained using a trial frame among the Health Science students at the University of Limpopo.

## 4. HYPOTHESIS

i. Heterophoria results of the phoropter at distance and near will not be different to those of a trial frame at distance and near.

## 5. ADVANTAGES OF THIS STUDY

Knowledge of whether subjective heterophoria measurements at far and near using a phoropter and trial frame are the same will be established as the subjective heterophoria at far and near will be measured. In case where the findings are reliable, recommendations for the daily use of a trial frame during eye examination will be communicated to the relevant bodies.

# CHAPTER TWO

## 2. LITERATURE REVIEW

### 2.1 Introduction

Heterophoria is the locus of intersection of the lines of sight, measured with respect to the object of regard, in the absence of a fusional vergence response (Rosenfield et al., 1997). Measuring this parameter is a standard clinical procedure and is typically assessed subjectively by providing non-fusible stimuli to the two eyes. Grosvenor (2007) alluded that heterophoria may be clinically linked with the patient's symptoms such as blur, headache, eyestrain and diplopia. These symptoms may be experienced at near, at far or at both distances. As a result, accurate and repeatable clinical findings of heterophoria are significant in the diagnosis and management of accommodative and vergence disorders (Rainey et al., 1998; Wong et al., 2002). The amount of heterophoria is expressed in prism dioptres ($\Delta$) (Schroeder et al., 1996) and according to Rainey et al (1998) the measurement of this parameter is commonly done subjectively.

### 2.2 Horizontal Heterophoria

During binocular viewing, the horizontal deviations are compensated by the fusional vergence. The amount and the direction of the horizontal heterophoria determines the amount and the type of the fusional vergence required (Sreenivasan et al., 2012). The use of the horizontal corrective prisms elicits the type of fusional vergence response needed to correct the heterophoria. The heterophoria will therefore change by the amount equal in power and the direction opposite to that of the corrective prism (Ying & Zee, 2006). The presence of exophoria stimulates an increase in the fast fusional convergence while the presence of esophoria stimulates an increase in the reflex fusional divergence to compensate for the uncontrolled heterophoria (Rosenfield et al., 1997).

### 2.3 Vertical Heterophoria

According to Jackson and Bedell (2012) the tendency of one eye to deviate vertically when the fusional vergence is broken and the inability of the fusional vergence to sustain single vision is referred to as vertical heterophoria. Small amounts of vertical heterophoria have been linked to symptoms such as double vison, asthenopia, loss of place while reading, drowsiness and fatigue. Scobee and Bennet (1950) reported that 35% of their sample of 1476 clinical patients had a vertical heterophoria of 0.5 prism dioptres, and they never complained of symptoms. The prevalence of vertical heterophoria in asymptomatic clinical patients and in non-clinical samples was found to range from 10-20%. The presence of vertical heterophoria is unrelated to age or refractive error. Vertical prisms are used to correct the heterophoria once identified (Jackson & Bedell, 2012). The direction of the vertical prism to be used depends on the type of the vertical heterophoria identified, either hyperphoria or hypophoria. According to Amos and Rutstein (1987) vertical heterophoria exists in normal individuals up to one prism dioptre. The significant vertical phoria has been found to be associated with symptoms of motion sickness.

### 2.4 Prevalence of Heterophoria Globally

According to Su et al. (2020), the prevalence of heterophoria is different from one country to the other, from geographic regions, and ethnics, and it ranges from 4.0% to 80.2%. They conducted a study among the Tibetan grade one learners. The aim of the study was to find the prevalence of heterophoria and also its associated factors. One thousand nine-hundred and forty two learners aged between 6 to 10 years took part in the study. Females were 981 (52.97%) and males were 871 (47.03%) and the prevalence of heterophoria was found to be 22.89%. At distance the heterophoria prevalence was found to be 4.64%, exophoria 4.21% and esophoria 0.43% respectively.

For near distance the prevalence was found to be 22.73% for heterophoria, 22.73% exophoria and 0.38% for esophoria. Su et al., (2020), did not detect any vertical heterophoria both at distance and near vison. Heterophoria at near was found with a mean of -7.63±5.15 Δ and -4.84±5.94 Δ. The study concluded that the grade one learners in the Tibetan, China had low heterophoria (Su et al., 2020).

However the disadvantages of this study by Su et al., (2020), includes the use of the Maddox rod which is too subjective for young children. Secondly, the use of the Maddox rod for both distance and near vision instead of using it for distance vision only. The use of a longitudinal study design instead of a cross-sectional study design was going to be more appropriate for such a study. Lastly the fact that the examiners were optometry students who are not fully competent could have an impact on the produced results or the results may be found to be different from those produced by experienced qualified practitioners.

Darko-Takyi et al., (2021) conducted a cross-sectional study in the Central Region of Ghana schools. The study was aimed at determining the expected binocular visual function data among schoolchildren aged between 11 and 17 years. A comprehensive binocular vision testing was conducted amongst 1261 normal participants. Cover test both at distance and near, and modified Thorington were conducted for the evaluation of heterophoria (Darko-Takyi et al., 2021). According to the study for cover test the distance heterophoria was found to be 0.12±0.79 exophoria, at near heterophoria was found to be 2.1±2.3 exophoria. With modified Thorington at near heterophoria was found to be 1.9±2.5 exophoria. The findings of the study were found to be within the expected data to be used by optometrists when dealing with Black Africans of the same age (Darko-Takyi et al., 2021).

Darko-Takyi et al., (2021), acknowledged that the reliability and validity of certain test measurements were not analyzed using statistical methods and this disadvantaged the study. As a result it is difficult to use the population's expected data for a single patient and it is a major limitation for studies with normative data. Another problem is that most of the techniques performed in this study (Darko-Takyi et al., 2021) were performed in free space which made it difficult for the target to be maintained steadily.

Akpe et al. (2014), conducted a cross-sectional study in Benin City, Nigeria among the 2139 primary school learners aged between 8 to12 years. The aim of the study was to determine the prevalence and patterns of strabismus and heterophoria among the primary school children. Participants were 1024 (47.87%) males and 1115 (52.13%) females. The overall prevalence of heterophoria was found to be 57.04% according to the study. At near the prevalence of heterophoria was found to be 23% while at distance it was found to be 53.62% (Akpe et al., 2014).

Exophoria was found to be more prevalent at near (12.16%) than esophoria at near (10.84%) (Akpe et al., 2014). The heterophoria at near was found to occur more in males than in females and the difference was found to be statistically significant, $\chi 2=6.79$, P-value=0.009. According to the study there was no hyperphoria or cyclophoria found amongst the participants. At near esophoria ranged from 3 to 11 Δ while exophoria at near ranged from 2 to 16 Δ (Akpe et at., 2014).

However, this study by Akpe et al., (2014) also had limitations or disadvantages. The study was conducted in the hospital and this renders it skewed since the data may not be a representation of prevalence rates in the community. A follow up study should be conducted in the community to evaluate if the results would be the same.

A study (Leone et al., 2010) was conducted among the school going children aged between 6 and 12 years. The aim of the study was to establish the prevalence of heterophoria and its association with refractive error and ethnicity in a population-based study of Australian schoolchildren. Exophoria was found to be more dominant at near and it was found to be 58.3% among the six-year-old group and 52.2% among the twelve-year-old group (Leone et al., 2010). At distance, 85.4% of the six-year-old and 90.9% of the twelve-year-old groups were found to have orthophoria. Esophoria was found to be rare at distance with a prevalence of only 1.0% among the six-year-old and 1.3% among the twelve-year-old groups. A near esophoria was found to be of low prevalence, 9.2% and 10.4% among the six-year-old and twelve-year-old groups respectively (Leone et al., 2010).

The study also indicated an increase in percentage of orthophoria among the twelve-year-old group, and a significant reduction in exophoria among the twelve-year-old group (7.8%) compared with the six-year-old group (13.5%) at distance (Leone et al., 2010). Vertical heterophoria was detected in few children at both distance and at near, and it was mostly found coexisting with the horizontal heterophoria (Leone et al., 2010). According to the study findings exophoria was found to be more predominant at near than at distance (Leone et al., 2010).

Fusional amplitudes and the frequency of heterophoria were evaluated among 111 Khatam-Al-Anbia Eye Hospital patients (Razavi, Poor & Daneshyar, 2010). The participants between the ages of twenty and forty were evaluated with their best corrected visual acuity. According to the study, the frequency of heterophoria among adults was found to be 57.7%. The prevalence of exophoria was found to be 51.4%; esophoria 9.9%; Hyperphoria 3.6% and cyclophoria was found to be 0.9% (Razavi et al., 2010).

Alvarez and Puell (2010) conducted a cross-sectional study on 87 school going children with poor reading skills and 32 children were in the control group. The participants were recruited from eleven elementary schools in Madrid Spain in grades three to six, aged between eight and thirteen years. Measurements of both the distance and the near horizontal heterophoria were measured through their best optical correction using Von Graefe (Alvarez & Puell, 2010). According to the study, the mean distance and near horizontal heterophoria values were the same. However, the findings were less exophoric as compared to those found in previous studies which used the same method for measuring the horizontal heterophoria (Alvarez & Puell, 2010; Amos & Rutstein, 1987; Benjamin, 2006; Jackson & Bedell, 2012; Matheron & Kapoula, 2008; Rosner & Feinberg, 2005).

One hundred and fifty-two children aged six and seven years participated in a study on determining the prevalence of heterophoria; fusional vergence; divergence values and the relationship between heterophoria and fusional vergence in preschool children (Radakovic et al., 2012). Eighty-Five percent of the participants were males and sixty-seven percent were females. According to the study, the distance orthophoria was found to be more prevalent (93.4%), while esophoria and exophoria were equally distributed (3.3%). At near, the frequency of heterophoria was found among 84.2 % of the participants. Exophoria was more prevalent (73%), followed by esophoria (11.2%) and, 15.8% of the participants were orthophoric (Radakovic et al., 2012).

### 2.5 Prevalence of Heterophoria in South Africa

Wajuihian (2018) conducted a cross-sectional study in the Kwazulu-Natal province, South Africa, among 1056 school going children aged between thirteen and eighteen years. The study was aimed at determining the prevalence of heterophoria and at investigating its associations with fusional vergences and refractive errors. Participants were randomly selected from 13 high schools out of the 60 high schools in uMhlathuze Municipality. According to the study, for distance the prevalence of orthophoria was 80.1%, that of exophoria was 13.9% and esophoria was the lowest with a percentage of 6.0% (Wajuihian, 2018). At near, the exophoria was the highest with a prevalence of 51.3% followed by orthophoria 36.6% and esophoria was the least with a percentage of 12.1%. For vertical heterophoria, the prevalence was 2.7% at distance and 3.6% at near. According to this study, both the horizontal and vertical heterophoria measurements were not normally distributed. Orthophoria was found to be more prevalent at distance, and exophoria more prevalent at near (Wajuihian, 2018).

In another study conducted by Wajuihian (2018), the subjects were the high school population in the Kwazulu Natal Province, South Africa. A multi-stage random cluster sampling was used, and 1211 children (481 males and 730 females) between 13 and 18 years of age, participated in the study. The purpose of the study was to determine the normative values for stereoacuity, accommodative and vergence measures. According to Wajuihian (2018), for near fusional ranges and for the aspects of heterophoria the distribution patterns were found to be closer to a normal distribution.

According to the study (Wajuihian & Naidoo, 2011), the following techniques were used to assess the different visual function. The LogMar acuity chart for visual acuity; static retinoscopy for refraction; cover test for ocular alignment; RAF rule for the near point of convergence; ±2 D flipper lenses for accommodation facility; the push-up method for amplitude of accommodation; trial lenses for accommodation posture (MEM) and prism bars for vergence reserves. According to the study the prevalence of the visual defects for both dyslexic and non-dyslexic participants was similar and that the association between dyslexia and the vison variables cannot be inferred (Wajuihian & Naidoo 2011).Wajuihian and Naidoo (2011), found the prevalence of heterophria when comparing for the dyslexic and non-dyslexic participants to be as follows: Esophoria for near vision was found to be 3% vs 0% and exophoria was found to be 9.5% vs 0% for near vison.

Makgaba (2006) conducted a retrospective study in which heterophoria values were analysed. Data from 475 record cards of black South African patients aged between 18 and 30 years were analysed. These were the patients seen at the University of Limpopo Optometry clinic between the year 2000 and 2005. According to the findings of the study, distance horizontal heterophoria ranged from 16 Δ esophoria to 12 Δ exophoria with a mean of 0.74 Δ exophoria (SD=±2.84). Esophoria was found to range from 0.5 to 16 Δ with a mean of 3.08 Δ (SD=±3.09) for distance vision. While exophoria ranged from 0.5 to 12 Δ with a mean of 2.21 Δ (SD=±1.82) for distance vision (Makgaba 2006).

At near the horizontal heterophoria ranged from 17 Δ esophoria to 15 Δ exophoria with a mean of 3.84 Δ exophoria (SD=± 4.80). The near esophoria ranged from 0.5 to 17 Δ with a mean of 4.88 Δ (SD=±3.41), whereas the exophoria at near ranged from 1.0 to 15 Δ with a mean of 6.30 Δ (SD=±2.58). Makgaba (2006) found the distance vertical heterophoria to range from 5 to 3 Δ right hyperphoria with a mean of 0.05 Δ right hyperphoria (SD=±0.76) whereas at near it ranged from 4 to 6 Δ right hyperphoria with a mean of 0.08 Δ right hyperphoria (SD=±0.96). According to Makgaba (2006), the heterophoria distributions both at distance and near were not normal. According to the study the distribution of both the vertical and horizontal heterophorias at distance and near was not normal. This was attributed to the fact that a majority of subjects were exophoric at both distance and near and for the vertical heterophoria the majority were found to be orthophoric both at distance and near (Makgaba 2006).

## 2.6 Different Techniques for Measuring Heterophoria

Schroeder et al. (1996) indicated that numerous methods can be used clinically to measure a patient's heterophoria namely: cover test (CT), the Von Graefe (VG) technique, Maddox rod (MR) test, the Modified Thorington (MT) method, stereoscopes and the Howell heterophoria card method. These techniques differ in the methods they use to achieve dissociation, in their ability to control accommodation adequately, in the level of proximal vergence induced, or in the manner by which they quantify heterophoria. These dissimilarities can yield different heterophoria measurements results on the same patient (Schroeder et al.,1996).

The heterophoria tests are performed at 6m and 40cm with spectacle correction in place where applicable. When performing the tests at 6m there is depletion of any active accommodative convergence because the accommodative system is at rest when focusing at distance which is the opposite when focusing at a target placed at 40cm. However, when heterophoria is measured at near the accommodation systems are not at rest compared to when focusing at a distant target. In addition, proximal convergence due to the perceived nearness of an object can also be ruled out when the test is performed at far. When using the Maddox classification, therefore, the distance heterophoria is said to be equal to the remaining component which is the tonic vergence (O'Shea et al.,1998).

With the use of each technique, fusion must be broken in order for the dissociation of the eyes to occur efficiently. In CT, this is achieved through the occlusion of one eye, the VG technique uses the displacement of one image, MR is achieved by the distortion of one image, or by using different targets with stereoscopes (Rainey et al., 1998 and Casillas & Rosenfield, 2006). The amount of heterophoria obtained using different methods, is usually expressed through the manipulation of prisms. Most heterophoria measurement techniques are subjective, hence they rely on the patient's response (Rainey et al., 1998).

In a study by Goss and Rainey (1999), the correlation technique was used to analyse the different methods for measuring the angle of deviation. According to this study, the VG test results were found to be slightly more exophoric compared to the MR test results. Furthermore the study indicated that methods with the highest correlations were generally the ones similar in terms of the way the techniques were performed or the patient's fusional abilities. The inter-test correlations findings from the group with normal binocular vision were found to be lower than in the strabismic group. This was attributed to minute angles of deviation in the normal binocular vision group and also to normal binocular vision having different degrees of persistence of fusional vergence (Goss & Rainey, 1999). The results of this study therefore suggest that the numerous differences in the manner in which the techniques measuring the heterophoria correlate with one another contributes to the slight differences in the results yielded by the individual techniques.

In Schroeder et al. (1996), studies which examined the reliability of heterophoria measurements and have compared various tests of heterophoria measurements were reviewed. The different methodologies that were used for data analysis in each study reviewed made the comparison of studies to be difficult. As a result, correlation analysis showed a very high degree of association of the tests with retest results. According to the review, in some studies there was lack of agreement among the different heterophoria techniques. Schroeder et al. (1996) attributed the disagreements to a number of factors including techniques used, duration of dissociation, patient responses, the method of dissociation, kinesthesis, the level of illumination and examiner's biasness. According to Schroeder et al. (1996), the Maddox rod (MR) technique shows more exophoria at near compared to the Von Graefe (VG) test due to the inability to control accommodation adequately.

Cebrian et al. (2014) investigated the repeatability of the MT card used in the distance heterophoria measurements. In this study, by Cebrian et al. (2014) the MR test results were found to be the least repeatable test in relation to both examiners and therefore not recommended for clinical use. The distance heterophoria measurements for 110 participants were measured by two clinicians on two separate occasions. The findings of this study however, contradicts the findings of Schroeder et al. (1996), Goss and Rainey (1999), and that of Alvarez et al. (2006).

The recommendation that the MR technique is not a good clinical tool was based on the fact that its repeatability was poor even though the technique for MT was similar to the MR technique (Cebrian et al., 2014). The exophoric results yielded by the VG technique in comparison with other techniques was however attributed to the fact that the VG procedure begins with 12∆ base-in. As a result, the subjects turned to a vergence disparity response in trying to decrease the distance between the images, which yielded more exophoric results. Whereas, during the MR technique the 12∆ base-in is only placed in front of the left eye only if the white spot and the vertical red line are not aligned (Cebrian et al., 2014).

## 2.7 Heterophoria Measurements using a Phoropter

Rainey et al. (1998) reviewed a number of studies published more than 40 years ago on heterophoria measurements using a phoropter. In these studies, the three methods commonly used for measuring heterophoria were performed using the phoropter and their results were compared. In one of those studies, heterophoria measurements from twelve participants were obtained using the VG, MR and MT techniques. The findings of the study indicated that, when both the degree of heterophoria and the variability of the reading are conducted with precautionary measures all the techniques yield accurate and consistent measurements with minute differences.

According to Rainey et al. (1998), the study further alluded that the important precautionary measure to be used is the utilisation of a dark room, specifically with the VG method. In the absence of the dark room, the test object should be placed against a bigger, unfigured wall or screen. Ordinarily, this tests may also be improved by alternating the cover between the eyes frequently while observing them. The differences from day to day will typically be more than the differences between the results of the different techniques and a consistent picture of the phoric condition can only be obtained by a number of observations through different conditions (Rainey et al., 1998).

In another South African (Limpopo) study, which was conducted by Mathebula et al. (2002), through the use of a phoropter, heterophoria measurements were obtained using the Maddox Rod technique. According to this study, in nine hundred children aged 6 to 13 years who were examined, the distance horizontal heterophorias were found to be narrower as compared to the study conducted by Makgaba (2005). However, Makgaba (2005) argued that the different findings between the two studies might be due to the age differences of the participants and also the dissociation techniques.

## 2.8 Reliability, Repeatability and Agreement between Different Heterophoria Methods

In the past, several studies have been conducted to evaluate the reliability, repeatability and agreement among the different heterophoria measurements. These comparisons have been made between tests, between sessions and between examiners. Railey et al. (1998), Wang et al. (2002) and Cebrian et al. (2014) studied the intra-examiner reliability of modified Thorington and the Thorington tests when compared with the Von Graefe and cover test. The authors found that the modified Thorington and the Thorington tests presents the highest correlation between examiners and the smallest limits of agreement. The Von Graefe test was found to produce more ex-values and high variations.

Anstice et al. (2021), examined the reliability and reproducibility of four clinical tests which measure horizontal heterophoria, the alternate prism cover test, the Von Graefe method, the Howell Card and Maddox rod. They also investigated the measurement agreement between examiners and whether the agreement fell within the prism limit of 4 Δ. The distance and near horizontal heterophoria of 20 visually-normal adults (age range 22-26 years) were measured by two examiners at separate visits. They found that the Howell card test had the lowest intra-examiner reproducibility, but at near the alternating prism cover test had better repeatability. They therefore concluded that the low repeatability of the heterophoria measuring techniques limits the ability to reliability defect the 4 Δ difference (Anstice et al., 2021).

## 2.9 Comparison of Heterophoria Measurements Using a Trial Frame and a Phoropter

Casillas and Rosenfield (2006), conducted a study in which they compared the subjective heterophoria measurements both at far and near using a phoropter and a trial frame. The study had 60 participants aged between 20 and 34 years of age. They alluded that the MR, MT and VG techniques yielded better repeatability when using a trial frame compared to when using a phoropter. Casillas and Rosenfield (2006), further indicated that VG method had poor repeatability with the use of a phoropter and subjects showed larger exophoric deviations measurements compared to the results of the other two techniques. They therefore, concluded that heterophoria measurements can be better quantified in a clinical setting using the MR and MT techniques through the use of a trial frame.

In a study conducted by Alvarez et al. (2006), distance heterophoria and distance fusional vergence ranges were established with the aim of providing normal values for comparisons. The heterophoria measurements at far were obtained using the VG method and the Risley rotary prisms were used for determining the fusional vergence ranges in each subject. The findings of the study revealed a slightly exophoric value for the distance heterophoria measurements in agreement with a number of studies conducted previously (Alvarez et al., 2006). The study also indicated that the distance heterophoria measurements found were independent of age.

## 2.10 Relationship Between Heterophoria and Refractive Error

Chen and Aziz (2003) conducted a study investigating the relationship between heterophoria and refractive error. Amongst the thirty-six subjects who took part in the study, eleven were short-sighted and twenty-five were emmetropic. The heterophoria was measured using the free-space phoria cards at five (25cm, 33cm, 50cm, 100cm and 300 cm) different working distances. Chen and Aziz (2003) found that with an increase in the working distance during the testing procedure, the amount of the heterophoria changed towards orthophoria irrespective of the type of the heterophoria the subject had.

According to Chen and Aziz (2003), the subjects, irrespective of whether they were emmetropes or myopes, did not show any significant difference in the degree of heterophoria. This was irrespective of their different viewing distances or in the type of heterophoria they possessed. The study concluded that there is no significant change in the amount of heterophoria measurements at different viewing distances irrespective of whether a person is an emmetrope or a myope (Chen & Aziz, 2003).

In another study by Maples and Harville (2009), the distance and near heterophoria measurements were compared using VG and MT techniques. The visual acuity and binocularity was tested for each participant and the sample was made of young adults who were optometry students. According to the study, the VG results were found to be more variable and considerably more exophoric when compared to MT findings both at far and at near. Based on the above statement, Marples and Harville (2009) suggested that the VG and the MT method cannot be considered as exchangeable techniques for measuring heterophoria. According to this study, the VG heterophoria findings usually supports the diagnoses of convergence insufficiency and that of convergence excess more often than MT findings (Maples & Harville, 2009).

In 2016, Jang, et al. (2016) assessed the distribution of near point convergence, near horizontal heterophoria, and near vergence among myopic children in South Korea. They examined one hundred and thirty-six school going children aged 8 to 13 years. A thorough visual examination was conducted for each participant. The examination included binocular vision tests; near point of convergence; push-up method; horizontal heterophoria measurements using the Von Graefe technique; distance and near negative and positive vergence through the use of a phoropter and the placement cards (Jang et al., 2016).

According to this study, 52 participants were found to have near esophoria. Eighty-four were found to have near exophoria, 53 had 0-6Δ exophoria and 31 presented with ≥ 7Δ exophoria. Of the 136 participants, 86 were found to have low myopia, 41 with medium myopia and nine presented with high myopia. Jang et al. (2016) found that there was higher correlation between esophoria and high myopia compared to medium myopia and low myopia. They also indicated that near esophoria is mostly related to hyperopia and near exophoria to myopia. Thus, correcting the different refractive errors should be able to ease the heterophoria symptoms.

Hitherto, there are no recent studies in the literature about the comparative study of subjective heterophoria measurements with a phoropter and a trial frame. Hence, the purpose of this study was to investigate the agreement of Von Graefe heterophoria measures using the phoropter and trial frame among university students.

# CHAPTER THREE

## 3. METHODOLOGY

### 3.1 Study Design

This was a quantitative descriptive study designed to compare heterophoria measurements obtained using the phoropter and trial frame at distance and near. The study protocol was approved by the University of Limpopo Research Ethics Committee (TREC/90/2019:PG). Written consent was obtained from all participants after they had been fully informed of the nature of the study according to the code of ethics in the Declaration of Helsinki protocol.

### 3.2 Participants and Study Setting

The target population for the study was the University of Limpopo School of Health Care Science students in the Limpopo Province. The sample comprised of students from five departments within the school. Three hundred and eighty-four students formed a sample screening size and were selected randomly from a list of all students within the School of Health Care Sciences.

Since the main aim of the study was to compare the heterophoria measurements found using a phoropter to those obtained using a trial frame, a sample of 88 participants were selected using the convenience sampling technique. Subjects were excluded from the study according to the following criteria: (1) health science students taking medication which tempered with their clear and comfortable vision from the case history, (2) Visual acuity worse than 6/6, (3) amblyopia and strabismus from cover test, (4) refractive errors of more than +/- 0.50, (5) students who refused to sign the consent form and (6) students not registered in the faculty of health sciences. Informed consent was obtained from each participant and volunteers following an explanation of the purpose, the methods of study and the possible side effects.

### 3.3 Sample size determination and justification

The study had two sample sizes, the first one was for the screening purpose and the second one was for comparison of two techniques. Sample size estimation for screening was meant to ensure that data collected was representative of the population. The information gathered from the screening was used to generalize findings from a drawn sample back to a population, within the limits of random error. Generally, the rule to acceptable margins of error in survey research is 5 - 10% (Suresh & Chandrashekara, 2012). Therefore, the screening sample size was estimated using the following formula ($N = Z_{\alpha/2}^2 * p * (1-p) / MOE$).

The prevalence of the interest of study is represented by P, E represents the precision (or margin of error) with which a researcher wishes to measure something. E will generally be 10% of P and Za/2 is normal deviate for two-tailed alternative hypothesis at a level of significance; for example, for 5% level of significance, Za/2 is 1.96 and for 1% level of significance it is 2.58. MOE is the margin of error indicating how close the findings of the study will be if the study is repeated a number of times. The screening sample was 384 as estimated by the sample size estimation formula.

For the comparison of the two techniques the sample size was calculated using the formula $n=(Z_{\alpha/2})^2P(1-P)/d^2$. The formula is normally used for calculating the sample size for studies with binary test outcome (Hajian-Tilaki, 2014). The sample size was calculated from estimating the sensitivity and specificity of the new diagnostic tool which in the present study were both estimated as 85%. Using these in the above equation the sample size was found to be 88.

## 3.4 DATA COLLECTION

### 3.4.1 Data Collection Approach and Methodology

The tests were conducted through the use of a phoropter and a trial frame, a specially designed recording sheet for the research was used to record the test results (**Annexure 3**). Section A of the recording sheet was used for recording the participants' demographic information and Section B was used for recording findings of the different procedures conducted. The tests conducted included; distance and near visual acuity; cover test; subjective refraction and Von Graefe heterophoria measurements using the phoropter and a trial frame.

The data tools and the data collected were stored electronically on the computer using an encrypted password. Three different locations were created for the storage of data tools and collected data. The aim of creating three different locations was to ensure that data was readily available in case one of the folders was unusable or corrupted.

The raw data was locked in the researcher's lockable cupboard and will be kept for a period of five years.

## 3.5 Materials and Procedures

Participants were given a comprehensive visual examination which consisted of a number of tests. Tests conducted included measurements of visual acuity, pupillary distance, cover test, subjective refraction and Von Graefe heterophoria measure. However, visual acuity measurements, cover test and subjective refraction were conducted for screening purposes. All measurements were taken both at far (6m) and also at near (40cm or 0.4m). Procedures and the testing environment for all the study participants were standardised and each procedure was conducted two times by the researcher.

The Von Graefe was performed first through the use of a phoropter and then through the use of a trial frame. All visual examinations were conducted between mornings 08h00 am and 11h00 am over a period of six months. The test conditions including testing distance, room illumination and targets used were the same for all participants.

### 3.5.1 (VA) Visual Acuity Measurements

The purpose of the test was to measure the baseline resolving power of the eye for distance and near objects.

### 3.5.2 Cover Test

The purpose of the test was to objectively evaluate the presence and direction of heterophoria.

### 3.5.3 Subjective Refraction

The purpose of the test was to subjectively determine the refractive error of the patient.

### 3.5.4 Heterophoria Measurements

For horizontal heterophoria the phoropter's Risley rotary prisms and trial frame handheld rotary prisms were used for testing. Measurements were recorded in prism diopters. When testing at 6m, an isolated 6/6 letter served as the target, whereas testing at 40cm (0.4m), participants viewed the 6/6E line of letters at near. The inter-pupillary distance (IPD) was measured. While viewing through the habitual distance refractive correction, a 12Δ base-in prism was introduced in front of the right eye and a 6Δ base-up prism before the left eye. For all measurements at distance and near, participants were instructed to look at the non-moving image and to keep the letters clear at all time. For horizontal measurements, the magnitude of the 12Δ base-in was reduced until the participants reported that the two images appeared aligned beneath the other. The amount of the horizontal prism that brought the diplopic images into precise vertical alignment was recorded as the horizontal heterophoria.

For vertical measurements, the magnitude of the 6Δ base-up was reduced until the participants reported that the two images appeared aligned side by side. The heterophoria was recorded as the vertical prism that brought the diplopic images into precise horizontal alignment.

# CHAPTER FOUR

## 4.1 RESULTS

### 4.1.1 Visual Acuity (VA)

The inclusion criteria consisted of participants whose visual acuities were 6/6 (20/20) or better with the habitual vision which is equivalent to 0.0 LogMAR at distance and near. All participants who could not achieve that requirement were excluded from the study and referred to the optometry clinic for a comprehensive eye examination. Most participants 89.89% had 6/5 visual acuity and only 10.2% had 6/6.

### 4.1.2 Descriptive Statistics

The study was done on 88 participants, 58 (65.9%) were females and 30 (34.1%) were males. Their ages ranged from 18 to 39 with a mean of 21±3 years of age. Table 1 shows the descriptive statistics of the Von Graefe heterophoria measurements using the phoropter and trial frame. The values of the median, skewness and kurtosis are also included. The mean heterophoria measurements for distance vision were 0.39±2.04 with a phoropter and 0.38±1.79Δ with a trial frame, $p > 0.05$. The mean vertical heterophorias were 0.18±0.74Δ and 0.13±0.42Δ with the phoropter and trial frame, respectively, $p > 0.05$. The mean horizontal heterophoria at near vision with the phoropter was 3.69±3.25Δ and 4.13±3.27Δ with the trial frame, $p > 0.05$.

Skewness and kurtosis are two important characteristics that describes the shape of a probability distribution (Sharma & Bhandari, 2015). Skewness shows if the distribution is symmetric or not. A skewness of zero shows that the distribution is symmetric. If skewness is greater than zero that is called *right-skewed*, meaning the right tail is longer than the left tail (Sharma & Bhandari, 2015). A *left-skewed* distribution has a left tail longer than the right one and the skewness value is less than zero (see Table 1 and figures 1-5). Kurtosis of a normal distribution is 3. A distribution with kurtosis less than 3 is *platykurtic* (Sharma & Bhandari, 2015). This means the distribution produced fewer and less extreme outliers than does the normal distribution. The distribution with a kurtosis more than 3 is said to be *leptokurtic* and produces more outliers than the normal distribution (see Table 1 and figures 1-5) (Sharma & Bhandari, 2015).

**Table 1**: Descriptive statistics for the heterophoria measurements using the phoropter and trial frame. Units are in prism diopters (Δ). Exophoria and hyperphoria were assigned positive while esophoria and hypophoria were given negative signs.

| **Statistic** | **Phoropter** | | | | **Trial frame** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Hfar** | **Hnear** | **Vfar** | **Vnear** | **Hfar** | **Hnear** | **Vfar** | **Vnear** |
| Mean | +0.39 | +3.69 | +0.18 | +0.03 | +0.38 | +4.13 | +0.13 | +0.07 |
| SD | 2.04 | 3.25 | 0.74 | 0.71 | 1.79 | 3.27 | 0.42 | 0.71 |
| Range | -6 to 8 | -5 to 15 | -1 to 1 | -3.to 1 | -4 to 6 | -4 to 15 | -1 to 1 | -3 to 2 |
| Median | 0.00 | 4.00 | 0.00 | 0.00 | 0.00 | 4.00 | 0.00 | 0.00 |
| Skewness | 0.33 | 0.23 | 4.13 | -1.88 | 0.38 | -0.11 | 0.77 | -0.90 |
| Kurtosis | 2.01 | 1.54 | 1.87 | 7.23 | 0.23 | 1.12 | 1.87 | 5.24 |
| **IQR** | | | | | | | | |
| 25 | 0.00 | 0.00 | 0.00 | 0.00 | -1.00 | 2.00 | 0.00 | 0.00 |
| 50 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 4.00 | 0.00 | 0.00 |
| 75 | 2.00 | 6.00 | 0.00 | 0.00 | 2.00 | 6.00 | 0.00 | 0.00 |

**Hfar** and **Vfar** represent horizontal and vertical heterophorias at distance vision, while **Hnear** and **Vnear** represent horizontal and vertical heterophorias at near vision.

Figure 1 shows the box plot of heterophoria measurements. Each box plot shows the median as a horizontal bold line inside the box and the interquartile range (IQR) between 25th to 75th percentiles as the length of the box (see Table 1). The line extending from the top and bottom of the box is called the *whiskers*, which represent the minimum and maximum measurement and they are 1.5 times the IQR from either end of the box. Measurements greater than 1.5 times IQR are outliers represented by circles while those represented by asterisk are extreme outliers and are 3 times the IQR.

The box plot shows the median as a horizontal line inside the box and the interquartile range (IQR) that ranges between 25th to 75th percentiles as the length of the box. A box plot that is symmetric with the median line approximately in the center of the box with symmetric whiskers that are slightly longer may have come from a normal distribution (see Figures 2-5). The horizontal heterophoria measurements using the phoropter and trial frame were not normally distributed. Table 1 shows that they were positively skewed with leptokurtosis. Both near horizontal heterophoria had near zero skewness but were more leptokurtic. The vertical heterophorias had very small deviation, rarely more than 2Δ.

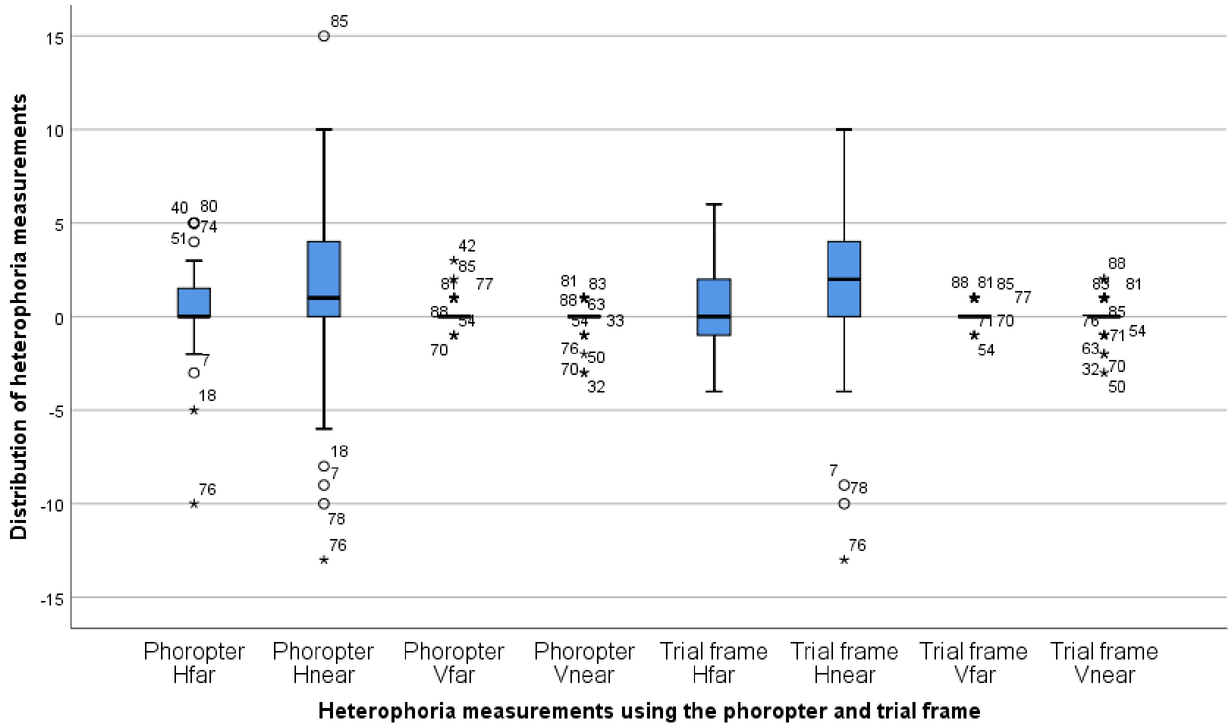


**Figure 1:** Box plot for the measurements of horizontal heterophorias using the phoropter and trial frame. Distance horizontal heterophoria were positively skewed and leptokurtic. The near horizontal heterophorias had more outliers but were positively skewed. Both the distance and near vertical heterophoria were very small and hardly seen.

The distribution of horizontal and vertical heterophoria measures are presented in Figures 2 to 5. The histogram graphs plotted the von Graefe heterophoria measurements against their frequency. The histograms provide information about the bell shape of the graphs. For ease of comparison the histograms for similar heterophoria measurements are placed together.

(a) (b)

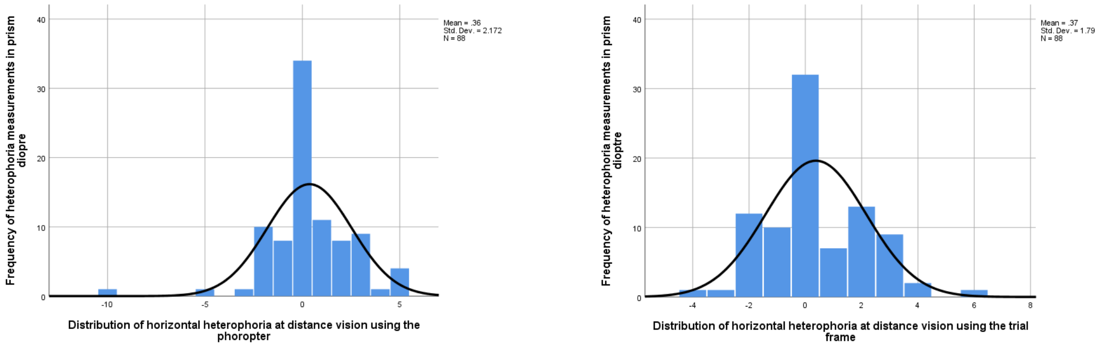


**Figure 2**: Histogram of distance horizontal heterophoria using the phoropter (a) and trial frame (b). Units are in prism dioptre.

(a) (b)

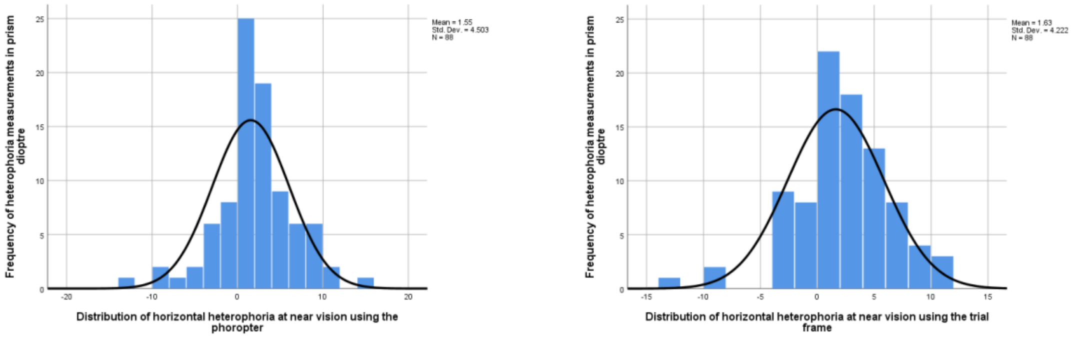


**Figure 3**: Histogram of near horizontal heterophoria using the phoropter (a) and trial frame (b). Units are in prism dioptre

(a) (b)

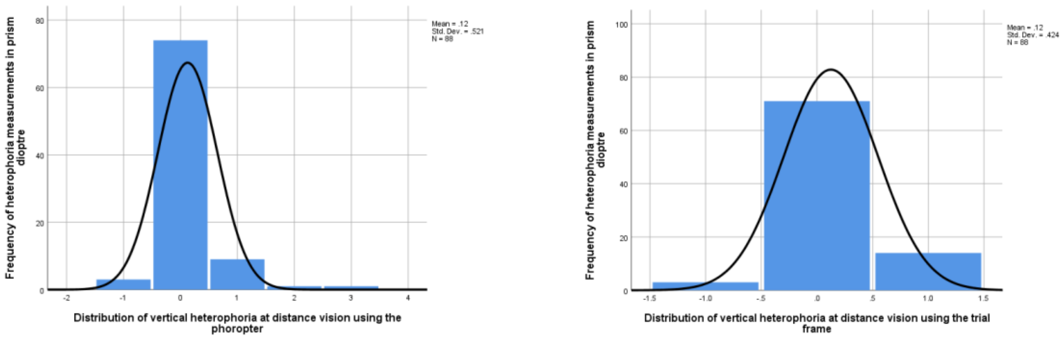


**Figure 4**: Histogram of distance vertical heterophoria using the phoropter (a) and trial frame (b). Units are in prism dioptre

(a) (b)

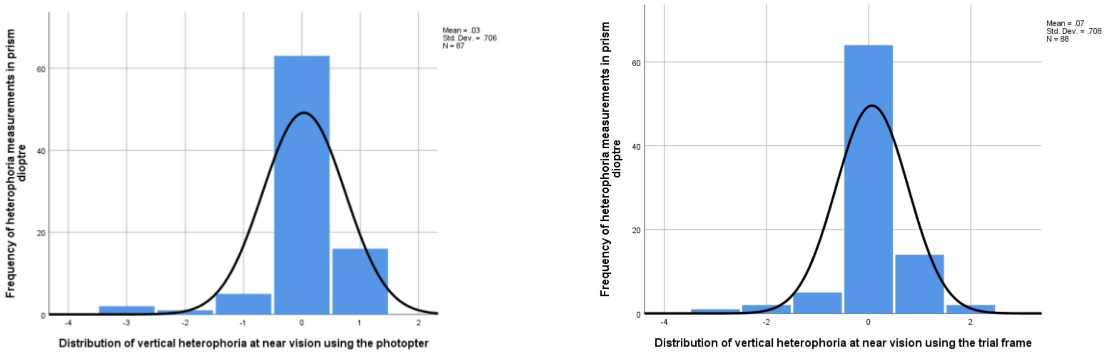


**Figure 5**: Histogram of near vertical heterophoria using the phoropter (a) and trial frame (b). Units are in prism dioptre

The relationship between the Von Graefe heterophoria measures using the phoropter and trial frame was evaluated using the correlation coefficient (*r)* between the results of the phoropter and trial frame (see Table 2 and Figure 6). The correlation showed the strength of the relationships of heterophoria obtained using the phoropter and trial frame. Giving an idea of the strength of the linear relationship and only interpreted if $p < 0.05$. Only the scatterplots of horizontal heterophoria were plotted.

Correlation analysis is a statistical technique to assess whether and how strongly pairs of variables are related. The main result of correlation is called the correlation coefficient or *r.* The numerical value of *r* ranges from-1 to +1. The closer the coefficients are to +1 or -1, the greater the strength of the linear relationship is. The linear regression can only be performed if the correlation exists and *r* can be interpreted only if the *p*-value is significant ($p<0.05$). Based on our results, there is a strong correlation of Von Graefe heterophoria measurements using the phoropter and trial frame. However, correlation quantifies the degree to which two variables are related and a high correlation does not automatically imply that there is a good agreement between the two methods.

**Table 2**: The coefficient of correlations between heterophoria measured using the phoropter and trial frame. The correlation of Von Graefe heterophoria were highly correlated. All the correlations were closer to 1. This correlation are interpreted when there is a significant difference.

| Paired heterophoria measures | Correlation (*r*) | Sig. |
|---|---|---|
| Horizontal heterophoria at far | 0.8 | 0.00 |
| Horizontal heterophoria at near | 0.8 | 0.00 |
| Vertical heterophoria at far | 0.9 | 0.00 |
| Vertical heterophoria at near | 0.9 | 0.00 |

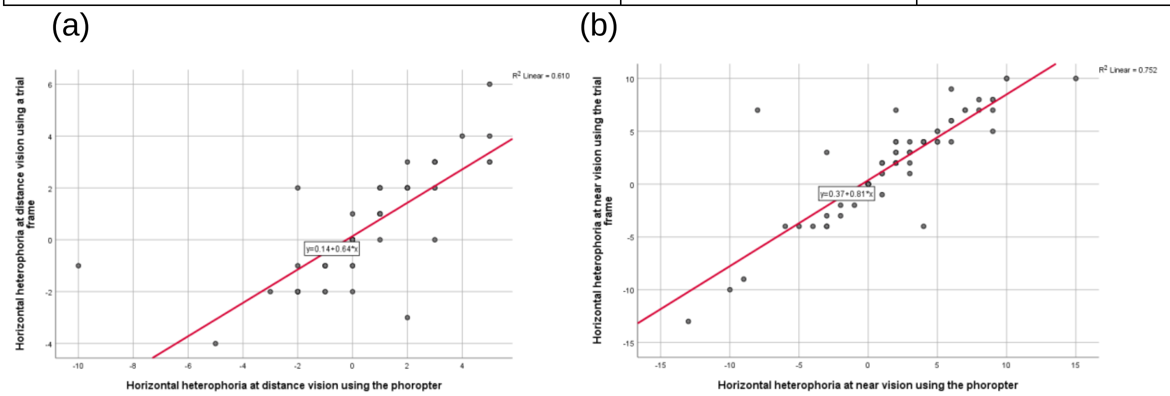


**Figure 6**: Scatterplots of horizontal heterophoria measurements at distance (a) and near vision (b)

Table 3 shows the mean differences among the distance and near heterophoria measurements. The mean differences were then used to generate the Bland-Altman plots. The plots are based on the means of the distance and near heterophoria measurements against their mean differences. The mean differences are represented by the red solid horizontal line, whilst the 95% limits of agreements (LoA) are represented by the bold upper and lower lines. The upper and the lower LoA are equal to the mean difference (*bias*) ± 1.96 *x* SD. Confidence interval of the LoA are represented by the dotted lines.

**Table 3**: The mean differences of heterophoria measurements

| Paired mean differences | Mean±SD | 95% confidence interval | | Sig. value |
|---|---|---|---|---|
| | | Lower | Upper | |
| Hfar | 0.01±1.29 | -0.262 | 0.285 | 0.934 |
| Hnear | -0.432±2.022 | -0.860 | -0.003 | 0.048 |
| Vfar | -0.057±0.613 | -0.073 | 0.187 | 0.387 |
| Vnear | -0.034±0.322 | -0.103 | 0.034 | 0.320 |

Hfar and Vfar are mean differences of horizontal and vertical distance heterophoria measures, while Hnear and Vnear are for horizontal and vertical heterophorias at near vision

Figure 7 to 10 show the Bland-Altman analysis for the heterophoria measurements using the phoropter and trial frame for distance and near vision. For distance horizontal heterophoria the differences between the two methods ranges over a total interval of 4.00 Δ. The interval of horizontal heterophoria at near vision ranged over a total interval of 8.00 Δ. The Bland-Altman graphs showed an overall mean difference of less than 2 Δ for all heterophoria measurements, however, the LoA for the horizontal heterophoria at distance vision fell outside the predetermined criterion of ±2 Δ. The near horizontal heterophoria and all vertical heterophorias had LoA within 2 Δ.

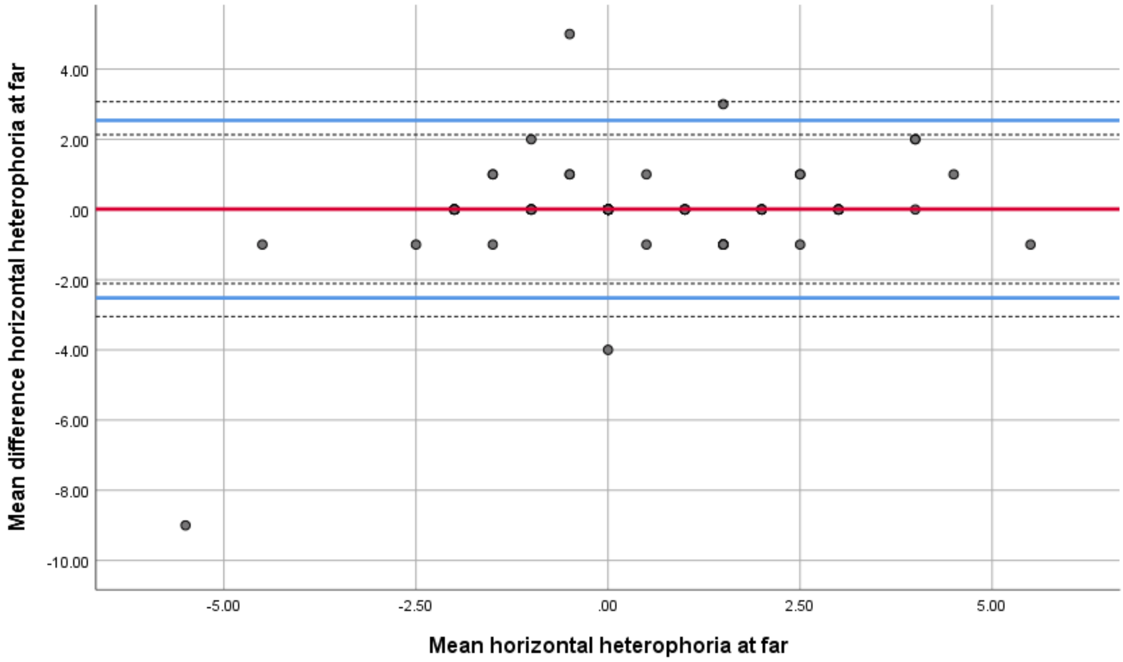


**Figure 7**: Bland-Altman graph showing the mean difference (red line) between the horizontal heterophoria measured at distance vision using the phoropter and trial frame. The red solid line represents the mean difference or is the reference line. The 95% limits of agreement are shown in blue solid lines while the confidence intervals are represented by dashed dots. Units are in prism dioptre.

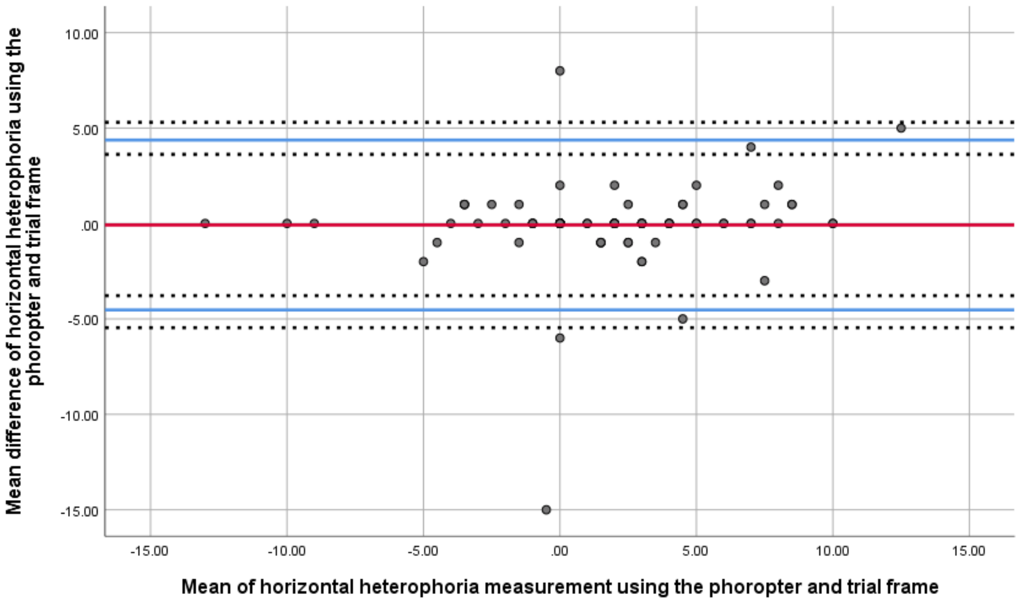


**Figure 8**: Bland-Altman graph showing the mean difference (red line) between the horizontal heterophoria measured at near vision using the phoropter and trial frame. The 95% limits of agreement are shown in dashed green lines. Units are in prism dioptre.

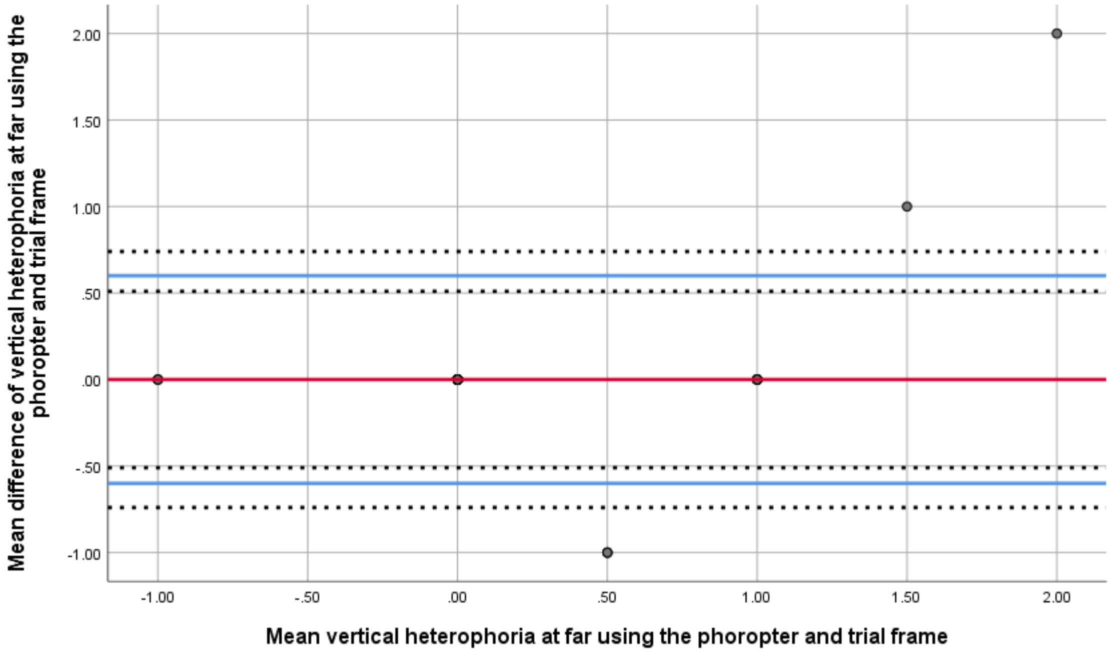


**Figure 9**: Bland-Altman graph showing the mean difference (red line) between the vertical heterophoria measured at distance vision using the phoropter and trial frame. The 95% limits of agreement are shown in dashed green lines. Units are in prism dioptre.

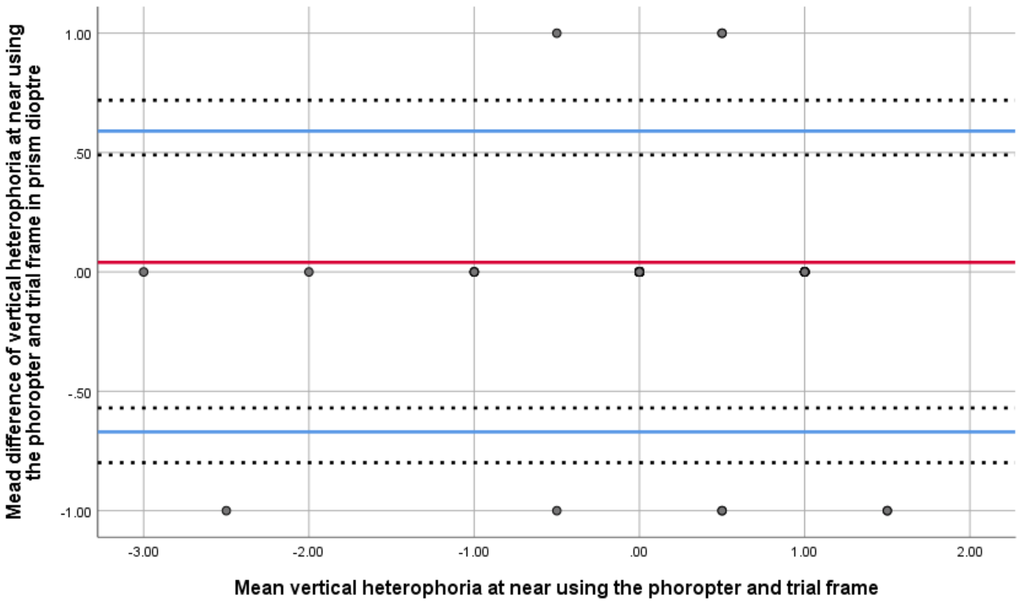


**Figure 10**: Bland-Altman graph showing the mean difference (red line) between the vertical heterophoria measured at near vision using the phoropter and trial frame. The 95% limits of agreement are shown in dashed green lines. Units are in prism dioptre.

Intraclass correlation coefficient (ICC) is one of the most commonly used indicators of reliability on quantitative data (Landers, 2015). Before any measurement instrument or tool can be used for clinical or research application, its reliability should be estimated. Reliability can be defined as an extent to which measurements can be replicated, and ICC is the reliability index. Reliability value ranges between 0 and 1, with values closer to 1 representing stronger reliability. ICC values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability and values greater than 0.9 indicate excellent reliability.

Since the 95% confidence interval of an ICC is 0.7, this can be regarded as good reliability. This is because the true ICC value can land on any point between 0.5 and 0.8. Average measure (Tavakol & Dennick, 2011) is the Cronbach alpha which provides a measure of the internal consistency of a test. It is also expressed as a number between 0 and 1. In this study, the Cronbach alpha is 0.7. The acceptable values of alpha range between 0.70 to 0.95.

| **Items** | **Intraclass correlation** | **95% confidence interval** | | **F Test with true value 0** | | | |
|---|---|---|---|---|---|---|---|
| | | Lower | Upper | Value | Df1 | Df2 | Sig. |
| Single measure | 0.2 | 0.2 | 0.3 | 3.7 | 8.6 | 602 | 0.00 |
| Average measure | 0.7 | 0.6 | 0.8 | 3.7 | 86 | 602 | 0.00 |

# CHAPTER: FIVE

## 5.1 DISCUSSION

Measurements of heterophoria is a standard clinical procedure, and they are influential in the diagnosis and treatment plan of binocular vision. It is typically assessed by presenting unfusible stimuli and determining the relative position of the two images. The heterophoria position is dependent on the level of the tonic convergence, accommodative position, proximal convergence and vergence adaptation (Griffin & Grisham, 1995; Rabbets, 2007; Rosenfield, 1997).

A wide variety of methods for measuring the subjective heterophoria are available. However, a study to investigate the agreement of heterophoria measurements using a phoropter and trial frame has not been done, according to our knowledge. Differences in the repeatability of heterophoria measurements had been reported and the Modified Thorington test was found to have a higher level of repeatability than either the Maddox rod or Von Graefe methods (Railey et al., 1998).

This study investigated the agreement of Von Graefe heterophoria measurements using the phoropter and trial frame. Two methods designed to measure the same variable should have high correlation. However, a high correlation does not automatically symbolize good agreement between the two methods. Based on the defined limits of maximum acceptable differences of 2 Δ, the study showed that the Von Graefe heterophoria measurement using either the phoropter or trial frame are comparable, and can be used interchangeably in the clinical setting.

The interpretation of Bland-Altman plot consists of a comparison of the 95% limits of agreement with a clinically acceptable difference between the two procedures. The difference of two to three prism diopters could be considered as a clinically acceptable difference. Casillas and Rosenfield (2006) reported that both Maddox rod and the modified Thorington tests are more repeatable when measured with a trial frame, however they did not compare the limit of agreement between the two procedures. The dissociation procedures of modified Thorington and Maddox rod tests are similar and this could be explained by the narrow 95% limits in their study, hence the modified Thorington and Von Graefe pair showed a wider limit because the dissociation procedures are different.

So in this study we compared Von Graefe heterophoria measurements using similar dissociation procedures to eliminate fusion and hence the 95% limits of agreement and mean differences were narrow (±2 prism diopters) and could be considered as clinically acceptable difference.

Casillas and Rosenfield (2006) compared the subjective heterophoria testing with a phoropter and trial frame. Distance and near horizontal and vertical heterophoria were measured on 60 visually normal subjects between 20 and 34 years of age. The authors then concluded that the use of a trial frame is more repeatable than when using a phoropter since the free space provides more repeatable responses.

When the eyes view a distant object, the visual axes of the two eyes are parallel with little or no accommodation. The majority of the 88 adult participants exhibited orthophoria when fixating at distance vision for both horizontal and vertical heterophoria, whether measured with a phoropter or a trial frame ($p$>0.05). The range of distance horizontal heterophoria extended from 6 esophoria to 8 exophoria. The results of this study agree with findings of several authors who also found orthophoria at distance vision (Dowley, 1990; Letourneau & Giroux, 1991; Mathebula et al., 2002). This shows that there is a high prevalence of distance orthophoria despite a large number of mechanical, neural and sensory variables (Mathebula et al., 2002).

When looking at near objects the eyes assume the active or functional position (Rabbets, 2007). According to Maddox classification, the fusional convergence brings the eyes from fusion-free or primary position to the active position (Griffin & Grisham, 1995; Rabbets, 2007). The convergent position assumed by the eyes at near relative to distance position is proximal convergence and accommodative convergence (Rabbets, 2007). The proximal convergence is induced by the knowledge that the object of regard is located nearer to the observer, while accommodative convergence is stimulated by the consensual linkage between accommodation and convergence. So accommodation and convergence determines the position of the visual axes while looking at near objects.

The means for the near horizontal heterophorias were 3.69Δ exo with the phoropter and 4.13Δ exo with the trial frame test. The mean difference was 0.4±2Δ esophoria with the phoropter than the trial frame (see Table 3). However, there was a strong correlation ($r$ = 0.8) between the near horizontal heterophorias measured using the phoropter and trial frame. Figure 6(b) Shows the scatterplot indicating that the difference is due to the magnitude of the heterophoria. Several studies have also found that the average near horizontal heterophoria is 3-6 exophoria (Canto-Cerdan et al., 2018; Walline et al., 1998).

Scobey and Green (1947) compared five different heterophoria measurement methods at near and suggested that these tests cannot be regarded as equivalent based on the means and standard deviations. This is also supported by Schroeder et al. (1996) who reviewed a number of heterophoria studies and stated that comparison of heterophoria measurements is complicated by inconsistent statistical analysis methods, such as descriptive statistics and regression analysis and these will not provide agreement among the results.

Casillas and Rosenfield (2006) obtained a significantly large exo deviations with the phoropter and trial frame both at distance and near. The rationale for this reduced vergence response observed when measuring heterophoria with Von Graefe technique is unclear. It seems unlikely to be produced by the reduced accommodative response and it is unlikely that the accommodative response would significantly be reduced when compared with either the Maddox rod or modified Thorington methods. Since the significant exo deviation was found at both distances, it seems likely that the results are from the decreased proximal or tonic vergence. Because the control of accommodation is one of the important factors that could affect heterophoria test results, it is evident that variations in target size could produce significant changes in accommodation and hence produce an erroneously elevated exophorias.

A vertical heterophoria occurs when the covered eye drifts up or down. Not much is known about vertical heterophoria but several papers reported that the prevalence of vertical heterophoria in asymptomatic individuals' ranges between 1-2 Δ (Letourneau & Giroux, 1991; Mathebula et al., 2002). Vertical heterophoria has been found to be associated with symptoms of motion sickness, dizziness and nausea (Amos & Rutstein, 1987; Benjamin, 2006; Jackson & Bedell, 2012; Matheron & Kapoula, 2008; Rosner & Feinberg, 2005). It may also cause symptoms of double vision, head tilt and eyestrain (Amos & Rutstein, 1987).

This study, showed that vertical heterophorias are smaller, seldom more than 1Δ and rarely more than 2Δ. The mean vertical heterophorias were 0.13±0.5 and 0.13±0.42Δ for distance vision using the phoropter and trial frame tests respectively ($p > 0.05$). The near ones were 0.08±1.8 and 0.07±0.7Δ for phoropter and trial frame respectively. The vertical heterophorias, both distance and near showed similar results, meaning it is less likely to change between distance and near vision (Makgaba, 2006; Mathebula et al., 2002; Rabbets, 2007). The small vertical heterophoria can give severe symptoms than the same horizontal one since the vertical fusional reserves are very small, rarely more than 4Δ than the lateral deviations (Amos & Rutstein, 1987; Benjamin, 2006; Jackson & Bedell, 2012; Matheron & Kapoula, 2008; Rosner & Feinberg, 2005).

It is unknown whether the phoropter does influence eye positioning during clinical testing. It has been reported that the vergence response produced by the phoropter may arise from the proximal vergences, differences in the head and eye position and restriction of the peripheral visual fields. Hokoda and Ciuffreda (1983) however suggested that the proximal vergence could contribute up to 50% of the total vergence response under open-loop conditions. Wick (1985) indicated that in some subjects, the output of proximal vergence could exceed that of the accommodative vergence.

London (1984) stated that the subjective heterophoria measurements taken through the phoropter would show either an increase in esophoria or a decrease in exophoria as a result of the effects of proximal vergence. However, there is no data presented to support this statement. The results of this study showed similar mean exo findings when using the phoropter and trial frame. This is not consistent with the proposal that the phoropter induced a larger proximal vergence response. In this study all measurements were taken with the fixation target in the primary position, hence the results are similar, and if there were possible differences they could not be explained by changes in the eye position**.**

Limitations of the study included the use of a single examiner for all the heterophoria techniques. Since the examiner knew about the previous test results, an unintentional bias might have influenced the study results. However, the potential bias was minimized by the fact that all tests were performed according to the standardized procedures. Sample was relatively small and habitual prescriptions were used rather than current subjective refraction or best determined compensation. Measurements were done on asymptomatic participants who were able to respond properly.

## 6. CONCLUSION

The findings of this study have demonstrated that the subjective measurements of horizontal and vertical heterophoria at distance and near using the phoropter and trial frame are interchangeable. The 95% limits of agreement were narrowest for the vertical both at distance and near and for the distance horizontal when measured with the phoropter and trial frame. However, there was wide limits of agreement of horizontal heterophoria at near. But the Von Graefe heterophoria measurements obtained using the phoropter and trial frame are clinically acceptable, and the two tests could be interchangeable in the clinical setting.

The advantage of the trial frame testing may influence the heterophoria measurements because it provides a more natural environment with a wider field of view, which may give more accurate cues for target depth and thus more accurate accommodation compared to the artificial environment created by the phoropter. Accordingly, we recommend that practitioners consider using the von Graefe method of heterophoria measurement using a trial frame as the method of choice for the clinical measurements of horizontal and vertical heterophoria (oculomotor deviations) at distance and near.

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## ANNEXURES

### Annexure A (Ethical Clearance)

**University of Limpopo**
Faculty of Health Sciences
Executive Dean
Private Bag X1106, Sovenga, 0727, South Africa
Tel: (015) 268 2149, Fax: (015) 268 2685, Email:kgakgabi.letsoalo@ul.ac.za

DATE: 04 March 2019

NAME OF STUDENT: TSOTETSI AL

STUDENT NUMBER: 9817470
DEPARTMENT: OPTOMETRY
SCHOOL: HEALTH CARE SCIENCES
QUALIFICATION: M.OPTOM

Dear Student

**FACULTY APPROVAL OF PROPOSAL (PROPOSAL NO. FHDC2019/2)**

I have pleasure in informing you that your M.OPTOM proposal served at the Faculty Higher Degrees Meeting on the 04 March 2019 and your title was approved as follows:

Approved Title: "A Comparative study of Subjective Heterophoria testing with a Phoropter and trial frame among Health Science Students at University of Limpopo, South Africa".

**Note the following:**

| Ethical Clearance | Tick One |
|---|---|
| Requires no ethical clearance<br>Proceed with the study | |
| Requires ethical clearance (TREC) (apply online)<br>Proceed with the study only after receipt of ethical clearance certificate | √ |

Yours faithfully

MR K.J Letsoalo
Chairperson

UNIVERSITY OF LIMPOPO
FACULTY OF HEALTH SCIENCES
2019 -03- 04
PRIVATE BAG X1106
SOVENGA 0727

CC: **Supervisor:** Mr JR Ramaja

**Co- Supervisor:** Prof SD Mathebula

Finding solutions for Africa

**Annexure B (Consent Form)**

**PROJECTTITLE: A COMPARATIVE STUDY OF SUBJECTIVE HETEROPHORIA TESTING WITH A PHOROPTER AND TRIAL FRAME AMONG HEALTH SCIENCE STUDENTS AT UNIVERSITY OF LIMPOPO, SOUTH AFRICA.**

**Researcher: MS. AL TSOTETSI**

**CONSENT FORM**

I, ______________________________________________________hereby voluntarily consent to participate in the following study: A comparative study of subjective heterophoria testing with a phoropter and trial frame among health science students at the University of Limpopo, South Africa. I realize that:

1. The study deals with eye examination and assessment of the refractive error of the participants;
2. The procedure or the treatment envisaged does not have risk factors;
3. The Ethics Committee has approved that individuals may be approached to participate in the study;
4. The research protocol, i.e. the extent, aims and methods of the research, has been explained to me;
5. The protocol sets out the risks that can be reasonably expected as well as possible discomfort for persons taking part in the study, an explanation of the anticipated advantages for myself or others that are reasonably expected from the study and alternative procedures that may be to my advantage;
6. I will be informed of any new developments that may become available during the study that may influence my willingness to continue as a participant;
7. Access to the records pertaining to my participation in the study will be restricted to persons directly involved in the study;
8. Any questions that I am have regarding the study, or related matters, will be answered by the researchers;
9. If I have any questions about, or problems regarding the study, or experience any undesired effects, I may contact a member of the research team;
10. Participation in this study is voluntary and I can withdraw at any stage;

11. If any medical problem is identified at any stage during the study, or when I am vetted for participation, such condition will be discussed with me in confidence by a qualified person and/or I will be referred to my doctor;
12. I indemnify the University of Limpopo and all persons involved with the above study from any liability that may arise from my participation in the above study or that may be related to it, for whatever reasons, including negligence on the part of the mentioned persons.

___________________________________ ___________________________

SIGNATURE OF THE PARTICPANT SIGNATURE OF WITNESS

Signed at _________________________ on ______ day of ___________ 2021

**Annexure C (Data collecting tool)**

**SECTION A: Demographic information**

| Serial Number | Age | Gender |
|---|---|---|
| | | |

**SECTION B: Procedures**

| VISUAL ACUITY | | | |
|---|---|---|---|
| VA @ FAR | Right Eye: | Left Eye: | Both Eyes: |
| VA @ NEAR | Right Eye: | Left Eye: | Both Eyes: |
| PD | @ FAR | @ NEAR | |
| COVER TEST | @ FAR | @ NEAR | |
| SUBJECTIVE REFRACTION | | | |
| Right Eye: | Left Eye: | VA OU: | |
| HETEROPHORIA MEASUREMENTS (PHOROPTER) | | | |
| HORIZONTAL | | VERTICAL | |
| FAR : | NEAR : | FAR : | NEAR : |
| HETEROPHORIA MEASUREMENTS (TRIAL FRAME) | | | |
| HORIZONTAL | | VERTICAL | |
| FAR : | NEAR : | FAR : | NEAR : |

**Annexure D (Budget)**

| Item | Cost | Total |
|---|---|---|
| Printing cartridge | R700/cartridge | R700 |
| Binding | R250 x 4 | R1000 |
| A4 Papers | R50 x 4 | R200 |
| Rotary Prism | R8721,96 x 2 | R17443.92 |
| Total | | R19343.92 |