A study to determine the use of cross cylinder in conjunction with the cross grid at distance as an alternative method for the duochrome technique amongst University of Limpopo optometry students.

By

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DECLARATION

I declare that the Dissertation hereby submitted to the University of Limpopo, for the degree of Masters (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 execution, and that all material contained herein has been duly acknowledged.

MAKGABA NT (MR) **Date**

DEDICATION

This dissertation is dedicated to my wife, Masefela Makgaba and my three lovely children (Madikela Makgaba, Molatelo Makgaba and Maeshela Makgaba) for their unconditional love, patience, encouragement, and support during the study period.

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DEFINITIONS OF TERMS

Accommodation: Is a process whereby changes in the dioptric power of the crystalline lens occur so that an in-focus retinal image of an object of regard is obtained and maintained at the highest resolution fovea (Grosvenor, 2007).

Astigmatism: A refractive anomaly in which the eye's optical system is incapable of forming a point image for a point object because the refracting power of the eye's optical system varies from one meridian to the other (Bennett, 2007).

Chromatic aberration: An aberration resulting when white light is incident on an optical system, in which light of different wavelengths is focused at different points along the optic axis (Tunnacliffe, 1993).

Circle of confusion: Is an optical spot caused by a cone of light rays from a lens not coming to a perfect focus when imaging a point source. It is also known as disk of confusion, circle of indistinctness, blur circle, or blur spot (Grosvenor, 2007).

Color vision: is the ability of a human eye to distinguish objects based on the wavelengths (or frequencies) of the light they reflect, emit, or transmit (Grosvenor, 2007).

Corrected visual acuity: Is the visual acuity in the better eye achieved by subjects tested with a pinhole or refractor (World Health Organization, 2009).

Cross grid: A target consisting of a radial dial or rotating T chat with the lines in the horizontal and vertical positions (Grosvenor, 2007).

Crossed cylinder test at near: A subjective test performed at a distance of 40cm while the patient wears his or her subjective lenses and a crossed cylinder with its minus axis at 90° (Grosvenor, 2007).

Duochrome: A test for subjective refraction that makes use of a chart having a red background on one side and a green background on the other side, taking advantage of the chromatic aberration of the eye (Grosvenor, 2007).

Emmetropia: A condition in which the incident parallel rays of light are brought to focus on the retina during minimal accommodation (Grosvenor, 2007).

Fogging: In subjective refraction, the use of sufficient plus lens power to place the image of a fixation target in front of the retina to prevent the patient from accommodating (Grosvenor, 2007).

Hyperopia: A condition in which the incident parallel light rays of light are brought to focus behind the retina during minimal accommodation (Grosvenor, 2007).

Myopia: A condition in which the incident parallel light rays of light are brought to focus in front of the retina during minimal accommodation (Grosvenor, 2007).

Optometrist: A primary healthcare practitioner who provides comprehensive eye and vision care, which includes refraction and dispensing, the detection/diagnosis and management of diseases in the eye and the rehabilitation of the visual system (Millodot, 2009).

Refractive end point: Is a state between myopia and hyperopia, in which ‘when parallel rays strike a physiologically normal eye, they are refracted so as to converge upon the retina, where they focus, forming a circle of least confusion with the eye in a state of rest (Duke-Elder 1978).

Refractive error: Occurs in the eye when accommodation is relaxed, and parallel rays of light fail to converge to a sharp focus on the retina. Categories of refractive error include short-sightedness, long sightedness and astigmatism (Grosvenor, 2007).

Retina: The light-sensitive tissue that lines the inner surface the eye (Tunnacliffe, 1993).

Vision 2020: The Right to Sight: is a global initiative established by the World Health Organization (WHO) and the International Agency for the prevention of blindness (IAPB), with an international membership of non-governmental organisations (NGOs). Professional associations, eye care institutions and corporations, which has set goals to eliminate preventable blindness by the year 2020 (World Health Organization, 2000).

Visual acuity: The resolving power of the eye, or the ability to see two separate objects as separate. The normal eye can resolve two objects as separate (with adequate illumination and contrast) if they are separated by an angular distance (Tunnacliffe, 1993).

LIST OF ABBREVIATIONS

D:	Dioptre
DC:	Dioptre cylinder
DS:	Dioptre sphere
IAPB	International agency for the prevention of blindness
JCC:	Jackson crossed cylinder
LCD:	Liquid crystal display
LoA:	Limit of agreement
LogMAR:	Logarithm of the minimum angle of resolution
NGO	Non-governmental organization
NM:	Nano meter
OD:	Oculus dexter (Right eye)
OS:	Oculus sinister (Left eye)
OU:	Oculus uterque (Both eyes)
TREC:	Turfloop Research Ethics Committee
VA:	Visual acuity

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ABSTRACT

BACKGROUND The measurement of the refractive end point plays a major role in the assessment of the refractive status of the patient. Currently, there are very few techniques if not one that can measure the refractive end point of the patient. The current method which is the duochrome technique is based on chromatic aberration. Until now there is no test for refractive end point that is not based on chromatic aberration. Therefore, it was against this background that the current study was undertaken to investigate an alternative for the duochrome technique to measure the refractive end point.

AIM OF THE STUDY The aim of this study was to establish the use of cross grid in conjunction with Jackson crossed cylinders at distance as a monocular refractive end point technique.

METHODOLOGY A cross-sectional analytic and descriptive study design was used. Sixty-four subjects (31 males and 33 females) were included in this study. Their ages ranged from 18 to 37 years with a mean of 20.75 years (SD = ± 2.67 years). The participants were University of Limpopo Optometry students. Ethical approval to perform this study was obtained from the Turfloop Research Ethics Committee (TREC) of University of Limpopo. All participants were made aware of the purpose of the study, and signed consent was obtained from each participant. All investigations and measurements adhered to the tenets or principles, belief and requirements of the Declaration of Helsinki. Optometric procedures performed included visual acuity, subjective measurement of refractive error, monocular refractive end point using duochrome technique and monocular refractive end point measurement using gross grid in conjunction with the cross grid. Data analysis was done using the Statistical

Package for Social Sciences (SPSS) Version 23. Paired sample t-test was performed on all the procedures.

RESULTS The uncorrected distance VA for the right eyes (OD) ranged from -0.30 LogMAR to 1.00 LogMAR with a mean of -0.25 LogMAR (SD = ±0.32). The nearest equivalent spherical powers (NSE = sphere +0.5 cylinder) for the right eye ranged from -4.25 to +4.25D (mean = -0.13, SD= ±1.09D) and from -4.50D to +1.00D (mean = +0.07 ±0.94D) for the left eye. After the removal of outliers, the refractive end point measurements with the duochrome technique for the right eyes ranged from -4.50D to 3.50D with a mean of -0.269, SD (±1.037) in bright illumination and from -4.50D to 4.50D with a mean of -1.914 (±1.101) in dim illumination. Subsequently, the NSE with the crossed cylinder in conjunction with the cross grid technique for the right eyes in bright illumination ranged from -4.75D to 4.75D with a mean of -0.481, SD (±1.037) and from -4.25D to 0.50D with a mean of -0.427 (±0.860) in dim illumination.

Sample Pearson correlation coefficients for end point with duochrome and crossed cylinder found that the highest correlation is between the duochrome in bright and cross grid in dim illumination (r = 0.701, p < 0.05), while duochrome in dim and cross grid in bright illumination had the lowest correlation (r = 0.659). The Bland–Altman plots showed that there was a good agreement between the duochrome methods and between the crossed cylinder method methods.

CONCLUSION the refractive end point measurements obtained from duochrome and cross grid are well correlated and comparable, suggesting that they could be used interchangeably in most clinical settings. However, caution is needed when using measurements obtained by cross grid method in dim illumination.

CHAPTER ONE

1. INTRODUCTION

It is recommended that one needs to have regular comprehensive eye examination at least once in two years (Sloan et al., 2005; McClure et al., 2016). The comprehensive eye examination includes a battery of tests such as measurement of refraction, accommodative and binocular vision tests. The duochrome technique forms an integral part in both monocular and binocular subjective refraction. It is well documented that not all people have normal colour vision (Neitz & Neitz, 2000). The duochrome technique requires the participants to differentiate the clarity of the letters on the green background against the letters on the red background. This requires normal colour vision. Rod monochromatism is a colour vision defect that results in total loss of colour vision, that is the person sees in black and white (Colligon-Bradley, 1992; Wee et al., 2010; Momeni-Moghaddam & Goss, 2014)

When duochrome is performed on a person with rod monochromacy, the practitioner relies on the grey scale. That is, the patient will have to differentiate the letters on the dark and the less dark background (Colligon-Bradley, 1992). It is believed that lack of colour vision will not affect the duochrome results as duochrome relies more on chromatic aberration of the eye as an optical system than colour vision (Gantz et al., 2015). Hitherto, this is the only method available to assess whether the person is over-plus or over-minused after monocular subjective refraction results (Colligon-Bradley, 1992, Grosvernor, 2007).

There is no information in the literature regarding utilization of cross grid test or Jacques blur point card at distance. However, there is extensive research on the utilization of Jacques blur point card at near. Hitherto, a study on the optics and application of the Jacques blur point card date back to 1956 (Egan, 1956).

Until now the cross grid is only utilized at near to measure the state of accommodation or for the determination of the tentative addition for patients with presbyopia (Brown, 1927; Fletcher, 1991; Friedman, 1940). Some of the recent projectors or Liquid Crystal Display (LCD) screens used for refraction and assessment of binocular vision boast a cross grid however, there is no information in the literature on what is the purpose of such cross grid. The results of the present study will show whether or not the cross grid can be used as an alternative for duochrome technique at distance.

1.1 Research Problem

Duochrome technique remains a test of choice to determine whether the participant is over-plused or over-minused following objective or subjective refraction (Cowan, 1938; Fletcher, 1991). Hitherto, it remains a method of choice regardless of the patient colour vision status (Bedford & Wyrszecki 1957; Millodot & Sivak, 1973).

Notwithstanding the reasoning that the duochrome technique applies to both individual with normal and those with impaired colour vision because the theory behind the technique depends solely on the wavelength thus green colour get refracted more than the red colour (Gantz et al., 2015). According to our knowledge, there is no study that tested the theory subjectively. Therefore, it is against this background that the current study conducted.

1.2 Research aim

To establish the possible use of cross grid in conjunction with Jackson cross cylinders at distance as a monocular refractive end point technique.

1.3 Objective

- To perform cross cylinder in conjunction with cross grid at distance.
- To perform duochrome technique at distance.
- To compare the results of cross grid at distance with those of duochrome technique, in all participants.

1.4 Hypothesis

The null hypothesis to be tested is: the results of the cross grid in conjunction with cross grid will not be different to those of duochrome technique.

The alternate hypothesis to be tested: the results of the cross grid in conjunction with cross grid will be different to those of duochrome technique.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Monocular Spherical end points

Once the astigmatism errors have been corrected with proper cylinder components, the remaining refractive errors are spherical. The refractive status is completed monocularly by determining the spherical powers that place the circles of least confusion of the eyes on their refractive retinal points in the distance fixation when accommodation is relaxed (Grosvernor, 2007; Benjamin, 2007).

To ensure that accommodation is controlled, the eyes are fogged by increasing the plus power or reducing the minus power of the spherical component of the prescription until several previously visible lines of the VA on the distance chart are blurred for each eye. The left eye is occluded and the right eye is fogged. Subsequently the right eye is unfogged in 0.25 DS steps until the spherical correcting lens produces maximum VA. Therefore, the examiner should show the patient a series of forced-choices (paired-comparison) presentations, extending into the minus, the patient subsequently selects the spherical lens power in each paired comparison that allows better VA. The end point of the right eye is reached when VA can no longer be enhanced by addition of minus spherical power or reduction of plus spherical power (Grosvernor, 2007). Then the left eye is unoccluded, the right eye is occluded and the process is subsequently repeated until the monocular spherical end point is reached for the left eye.

Insufficient unfogging places the focus of an eye in front of the retina, resulting in less than maximum VA because of residual myopia (Ladi, 2017). Too much unfogging places the focus behind the retina in a presbyopic eye because of residual hyperopia (Grosvernor, 2007; Benjamin, 2007).

2.2. Duochrome method

Chromatic aberration of the eye has been shown to be a possible basis for determining the spherical component of the refractive error (Grosvernor, 2007; Antona et al., 2008). The position of focus for maximum VA is that which places the smallest circle of least confusion of the yellow waveband of 570 nm on the retina. Duochrome was designed as a distance visual-acuity chart, often called a red/green chart. The chart was split equally into two identical halves, the letters on the right half of the chart had a red background and the identical left half had a green background. The background straddled the preferred yellow focus by approximately 0.25 D in front of the retina, where green light of 535 nm tends to focus 0.25 D behind the retina (Grosvernor, 2007).

The most common duochrome chart today is VA chart that is projected through a split red and green filter (Yanoff & Duker, 2009). Some devices present isolated letters, lines of letters or groupings of symbols instead of a typical acuity chart. Duochrome test is used essentially as a means of checking the final spherical end points in a monocular fashion for each eye. This is accomplished because near the end points, an eye that is residually myopic by a small degree of sphere power sees the letters having a red background appearing clearer and darker, with more defined borders. Conversely, the letters on the green background will appear slightly fuzzy and less dark, with less defined borders. An eye that is residually hyperopic by a small degree of sphere sees the letters on the green background to be clearer, darker and more defined. The residually emmetropic eye sees the letters on both sides of the duochrome chart to be of equal clarity, darkness and definition (Bennett, 2007).

Since the chromatic aberration involved is on the order of 0.50D between the red and green backgrounds, with normal focus halfway between the slightly fogged subject's initial report that the letters are more visible on the red background should switch to the green background with one or two increments of minus power in -0.25D increments. Often, at a spherical power increment between the "last red" report and the "first green" report, the subject should note no difference between visibility of the letters on the red and green backgrounds.

2.3. Cross-Cylinder test

Determination of the end point sphere power at distance may also be estimated by use of the Jackson Cross-Cylinder (JCC) lens, in a manner similar to that performed at near (Schneller, 1966). The invention of the cross cylinder can be traced back to the late 18th century (Jackson, 1887; Friedman, 1940). It was initially called the stoke lens which was designed to correct astigmatism. This lens was discovered in 1849 (Friedman, 1940). Even when the discovery of Jackson cross cylinder dates back in the late 18th century there is no study currently in the literature that dispute its optics. Many studies that exist in the literature are rather agreeing with the findings of Jackson (1887) thus broadening the application of the JCC (Egan 1956; Wee et al, 2010; Benjamin, 2006; Grosvernor, 2007).

The use of the cross cylinder in determining presbyopia and in prescribing the necessary corrective lenses was described by Jacques, an optometrist (Egan, 1956). The target he used was a cross printed on a card; each limb of the cross was made up of three heavy black lines. The test could be performed monocularly or binocularly. If the target is conjugate with the retina (that is, if the patient can adequately accommodate to the target), the vertical bar of the cross will fall as far "behind" the retina as the horizontal bar falls in "front" of the retina. The patient will report equal clarity or blurring of the bars of the target.

If, however, the patient is presbyopic (that is, cannot accommodate enough), the horizontal bar of the cross will fall closer to the retina than will the vertical bar; the patient will then report that the horizontal bar is clearer. This test is based on the assumption that the patient will suspend his accommodation between the bars of the cross when the cross cylinder is introduced (Egan, 1956). The test is not valid if the patient actively accommodates on one set of lines (Egan, 1956). When a subject fixate at a target at distance accommodation is not induced (Grosvernor, 2007). It is assumed that the astigmatism has to be fully and properly corrected. A target consisting of a radial dial or rotating T chat with the lines in the horizontal and vertical positions is presented and the Jackson cross cylinder (JCC) lens with its minus axis (red dots) at 90° is placed before the eye. The patient is fogged and asked whether the vertical or horizontal lines appear equally dark, black or clear, or whether the vertical lines appear more or less prominent than the horizontal lines.

The vertical lines should appear clear, because the interval of sturn is in front of the retina and the vertical lines are focused more closely to the retina than the horizontal lines. The vertical lines should continue to be clearer as the eye is unfogged until the end point sphere power is reached, at that point the JCC will have placed the images in the lines equally in front and behind the retina. The two sets of lines would seem equally clear or prominent. The vertical lines appear more prominent when the eye has been over-plussed or under-minused (fogged), such that the plus sphere should be reduced or minus sphere be added until equality is reached. The horizontal lines would appear more prominent when the eye has been over-minussed or under-plussed, such that the plus sphere should be increased or the minus sphere reduced (Grosvernor, 2007; Benjamin, 2007).

The problem with this test is when the minus lens power exceeds the amount that establishes equality. In such case the images can be restored to the retina by accommodation and may indicate equality for both sets of lines instead of a need for more plus or less minus sphere power. It is recommended that if the vertical and horizontal lines appear equal and remain so upon further reduction of plus or addition of minus power, plus sphere be added or minus sphere decreased until the vertical lines again appear more prominent. The plus power is then reduced until equality is first restored at the spherical end point.

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 Research design

This study was a descriptive quantitative whereby duochrome results were compared with those of cross cylinder in conjunction with cross grid.

3.1.1 Participants

Participants for this study were optometry students studying at the University of Limpopo. There were more than 150 registered optometry students at the university. Ethical clearance to perform this study was obtained from the Turfloop Research Ethics Committee (TREC) of University of Limpopo (**Annexure A**). All participants were made aware of the purpose of the study, and a consent was obtained from each participant by means of a signed consent form **(Annexure B)**. All investigations and measurements adhered to the tenets or principles, belief and requirements of the Declaration of Helsinki (Stockhausen, 2000).

3.1.2 Study sample and sampling method

Simple random sampling was used to get participants for this study. This method of selection of a sample comprises of *n* number of sampling units out of the population having N number of sampling unit (Yates et al., 2008). The sampling units were chosen with replacement in the sense that the chosen units were placed back in the population. Sample size was a function of significance level, power and magnitude of the difference (McCrum-Gardner, 2010). Assuming a two-tailed hypothesis, a 0.05

significance level, a 0.5 effect size, a 0.80 statistical power and a population of 200, the calculated sample was made of 64 participants.

3.1.3 Inclusion Criteria

- Each participant (subject) had at least aided VA of 6/6 or better in each eye and normal colour vision.

3.1.4 Exclusion criteria

- The participants that did not have binocular vision were excluded for this study because the tests in this study were performed both monocularly and binocularly.
- The participants that were taking medication that could interfere with accommodation were excluded for this study.
- Participants with ocular surgery or trauma and those wearing contact lenses were excluded for this study.

3.2 Procedures

3.2.1 Visual acuity

Visual acuity (VA) was measured with a subject sitting comfortably at a distance of 6m from the distance Snellen acuity chart. Each subject was asked to read the letters on the chart, firstly monocularly and then binocularly. The smallest line that the subject read was recorded as VA. If the subject missed less than half of the letters in that line, the number of letters were subtracted from the VA (**Annexure C**). For example, if the smallest line that the patient read was 6/6 and he missed two letters in that line the VA would be recorded as $6/6^{-2}$. If the subject was able to read some letters in the subjacent line, then the number of letters were added to the VA such as $6/6^{+2}$. Subsequently the VA was converted to LogMAR for easy analysis

(Moseley, 1997). The near VA was measured using the same procedure as the distance VA except that it was measured at a reading distance of 40cm using the Bailey-Lovie word reading chart. The near VA was subsequently recorded on the record form in LogMAR (**Annexure C**).

3.2.2 Colour vision assessment

Ishihara test plates were presented to each subject while they were seated in a full lit room. The plates were placed 40cm away from the subject's eyes and tilted so that the plane of the paper was at right angles to the line of vision. The correct position of each plate was indicated by the number which was printed on the back of the plate. The numbers which were seen on plates 1-17 are stated, and each answer was given within seconds. If the subject was unable to read numerals, plates 18-24 were used and the winding lines between the two X's were traced with the brush. Each tracing should be completed within ten seconds. The test was performed monocularly. The results were recorded on the record form (**Annexure C**)

3.2.3 Subjective refraction

Refraction was performed both monocularly and binocularly. During monocular subjective refraction, while testing one eye, the other eye was occluded. The VA chart was placed at 6 meters from the participant with normal ambient room illumination. A series of positive spherical, negative spherical and cylindrical lenses were used to compensate for the refractive error. Improvement in VA with best optical correction was recorded on the record card (**Annexure C**)

3.2.4 Duochrome

Starting with the results of the monocular subjective findings, the red and green filters (red on the left and green on the right side) were projected along with the side-by-side letter chart designed for use with the test. Participants were asked to report which of the letters were clear, sharper and blacker or more distinctive; those on the red background or those on the green background. The subject's attention was directed to the 6/9 (LogMAR results) letters. If the letters on the red background were more distinct than those on the green background, plus lens power was reduced in 0.25D at a time until the subject reported that the letters on the red and green background were equally distinct. In the instances where equality was not reported, a step before reversal was recorded as the end point. The test was conducted under dim and bright illumination.

3.2.5 Cross Grid at distance

The cross grid chart was projected at distance of 6m using Magnon CP-690 projector. Subsequently, a ±0.50 Diopter cylinder (DC) lens was introduced on the phoropter whereby -0.50 DC was along 90º and +0.50 DC was along 180º. The test was also conducted under dim and bright illumination. Subsequently, the subject was then asked to choose clear darker and sharper lines between the horizontal and vertical lines on the cross grid. When the subject reported that the vertical lines were clear, negative lenses were introduced in front of the subject's eye in 0.25 DS steps until the subject reported equality. Conversely, when the subject reported that the horizontal lines were clear, plus lenses were added in 0.25 DS steps until the subject reported equality. When the subject failed to report equality then a step before reversal was taken as an end point. The test was performed both monocularly and binocularly.

3.3 Data analysis

The results were recorded in a specially designed form for the research **(Annexure C)**. Data was analysed in SPSS software, version 23. The descriptive statistics, box plots, Pearson correlation and Bland-Altman method were performed. There are several tests for assessment of normality. For this study we used the Shapiro-Wilk test. Most studies used Kolmogorov-Smirnov test to assess the normality of data. However, Kolmogorov-Smirnov test is not the best choice for testing normality of data. It has been reported that it has low power and high sensitivity to extreme values (Ghasemi & Zahediasl, 2012; Razali & Wah, 2011).

CHAPTER FOUR

4. RESULTS

Sixty-four participants (31 males and 33 females) were included in this study. Their ages ranged from 18 to 37 years with a mean of 20.75 years (SD = ± 2.67 years). The participants were all University of Limpopo, Optometry students.

The uncorrected distance VA for the right eyes (OD) ranged from -0.30 to 1.00 LogMAR with a mean of -0.25 LogMAR (SD = ± 0.32), for the left eyes (OS) from -0.30 to 1.00 LogMAR with a mean of -0.27 LogMAR (SD = ± 0.28) and for both eyes (OU) from -0.30 to 1.00 LogMAR with a mean of -0.74 LogMAR (SD = ± 0.28). Table 1 presents the summary statistics of the uncorrected VA.

Table 1. Statistics of the uncorrected distance visual acuities (LogMAR).

Eye	**Distance VA (LogMAR)**	
	Range	**Mean (SD)**
OD	-0.30 to 1.00	-0.25 (± 0.32)
OS	-0.30 to 1.00	-0.26 (± 0.28)
OU	-0.30 to 1.0	-0.74 (± 0.28)

The nearest equivalent spherical powers (NSE = sphere +0.5 cylinder) for the right eye ranged from -4.25 to +4.25D (mean = -0.13, SD= ± 1.09D) and from -4.50D to +1.00D (mean = +0.07 ± 0.94D) for the left eye.

The descriptive statistics for end point through duochrome and cross grid in both bright and dim illumination are summarized below in Table 2. The results for both eyes have been included in Table 2(a). However, Table 2(b) presents the results for the right eye only without outliers. Twenty outliers were removed.

Paired sample t-test was performed on all the procedures. The test showed a statistically significant difference between the mean values obtained with the two methods ($p < 0.01$), which are duochrome and cross grid in bright illumination, and duochrome and cross grid in dim illumination. However, both the duochrome in bright and dim illumination did not show any statistically significant differences (**see Table 3**)

Table 2: Descriptive statistics for the measurement of refractive end point in diopters with the two different methods in both bright and dim illumination with outliers (a) and without outliers (b).

(a)

Statistics		**Duochrome**				**Cross Grid**			
		OD		OS		OD		OS	
		Bright	Dim	Bright	Dim	Bright	Dim	Bright	Dim
Mean		-0.269	-1.914	-0.375	-0.335	-0.481	-0.427	-0.582	-0.550
SD		1.037	1.101	0.907	0.876	1.211	0.860	0.921	0.860
95% CI	**Lower**	-0.528	-0.466	-0.601	-0.554	-0.783	-0.765	-0.812	-0.767
	Upper	-0.010	0.083	-0.148	-0.117	-0.117	-0.335	-0.352	-0.335
Minimum		-4.50	-4.50	-4.25	-4.00	-4.75	-4.25	-4.50	-4.25
Maximum		3.50	4.50	0.50	0.50	4.75	0.50	0.50	0.50
Skewness		-1.1448	-0.742	-2.711	-2.756	-0.417	-2.310	-2.307	-2.310
Kurtosis		8.866	10.082	7.831	8.094	8.692	6.447	6.031	6.447
IQR	**25**	-0.50	-0.25	-0.50	-0.50	0.50	-0.75	-0.50	-0.75
	50	0.00	0.00	-0.25	0.00	-0.25	-0.25	-0.25	-0.25
	75	0.25	0.25	0.00	0.25	0.00	0.00	00.00	-0.50

(b)

Statistics		Duochrome				Cross Grid			
		OD		OS		OD		OS	
		Bright	Dim	Bright	Dim	Bright	Dim	Bright	Dim
Mean		-0.091	-0.052	-0.135	-0.12	-0.29	-0.31	-0.35	-0.33
SD		0.38	0.38	0.36	0.39	0.39	0.43	0.47	0.45
95% CI	**Upper**	0.17	0.05	-0.034	-0.05	-0.18	-0.19	-0.22	-0.21
	Lower	-0.20	-0.16	-0.24	-0.23	-0.40	-0.44	-0.48	-0.46
Minimum		-1.00	-1.50	-1.00	-1.50	-1.25	-1.25	-1.75	-1.50
Maximum		0.50	0.75	0.50	0.50	0.50	0.50	0.50	0.50
Skewness		-0.64	-1.14	-0.42	-1.14	-0.27	-0.12	-0.89	0.55
Kurtosis		0.11	3.16	0.13	2.06	-0.47	-0.51	0.99	0.29
IQR	**25**	-0.25	-0.25	-0.25	-0.25	-0.50	-0.50	-0.50	-0.50
	50	0.00	0.00	0.00	0.00	-0.25	-0.25	-0.25	-0.25
	75	0.25	0.25	0.00	-0.25	0.00	0.00	0.00	0.00

Table 3: Paired mean difference of the duochrome and cross grid on the right eye only.

Paired Variables	**Mean**	**Standard deviation**	**95% Confidence Interval**		**Significance**
			Lower	**Upper**	
Duochrome bright and cross grid bright	0.20192	0.30130	0.11804	0.28581	0.00
Cross grid dim and duochrome dim	-2.6442	0.33363	-0.35731	-0.17154	0.00
Duochrome bright and duochrome dim	-0.3846	0.27920	-0.11444	0.3751	0.314
Cross grid dim and cross grid bright	-0.2404	0.28551	-0.10353	0.5545	0.546

Figure 1 shows the boxplots (box-and-whisker plots) of the refractive end points through the duochrome and cross cylinder method for both bright and dim illumination, (a) with outliers and (b) without outliers. The horizontal bold line in the middle of the boxes represents the median (50th percentile) of each distribution. The edges of the box above and below the median are the quartiles (25^{th} percent below and 75^{th} percent above). The box represents the middle most 50% of the distribution. Whiskers', one below the 1^{st} quartile and one above the 3^{rd} quartile. The whiskers indicate the lowest and highest values in each distribution. The boxplots showed that the distributions of the measurements for Figure 1b are roughly symmetrical. In Figure 1a the distribution of the measurements of the duochrome in bright illumination is skewed (see Table 1). The box plots in Figure 1a are smaller compared to figure 1b.

In Figure 1(b) the measurements of the duochrome in dim and cross grid in bright and dim illumination have measurements which are nearly distributed equally. The duochrome in bright illumination have narrower spread. However, the means of each duochrome and cross grid are equal both in bright and dim illumination (see Table 3). The subsequent analysis was performed using data without outliers and using only the measurements of the right eyes only.

(a)

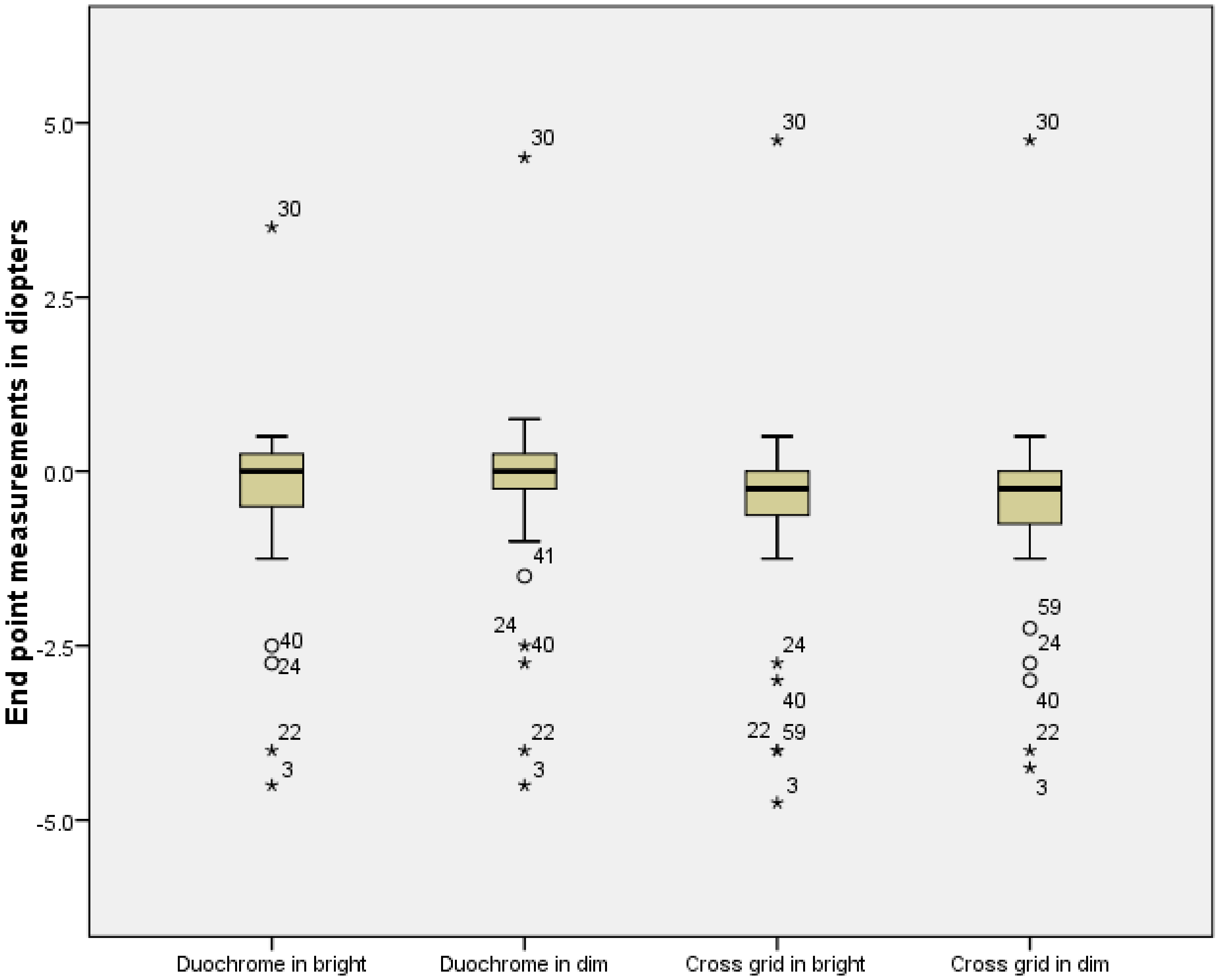


Figure 1(a) shows the box plots of the measurements with outliers.

(b)

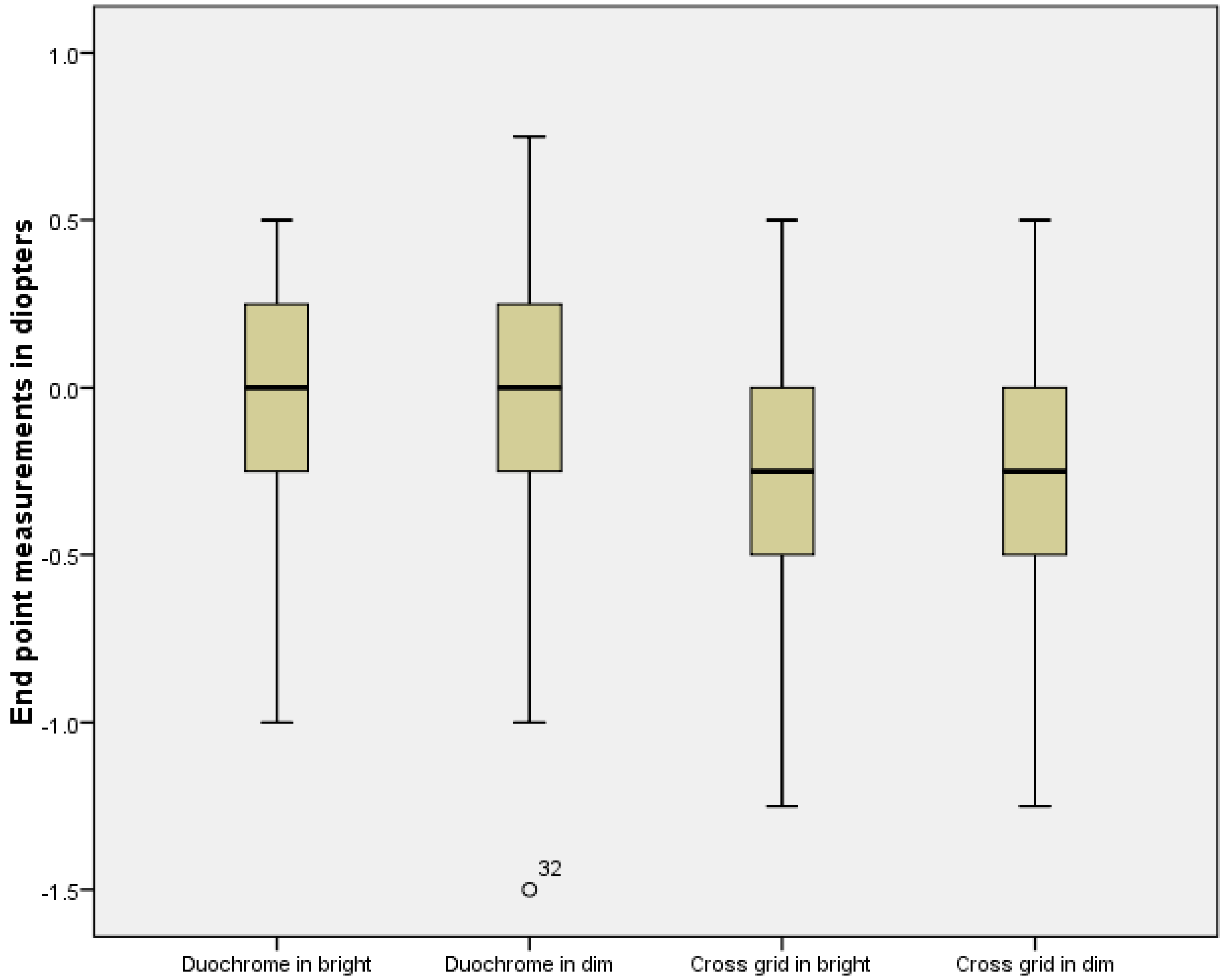


Figure 1(b) shows the box plots after the removal of outliers. The box plots for the duochrome technique were slightly higher than those of the cross grid, with more variability.

The relationship between variables were tested using the regression analysis (Table 4 and Figures 2 to 5). Pearson or product-moment correlation statistics was performed to evaluate how pairs of variables are related. The results of correlation are called correlation coefficient (*r*). The expected numerical values of *r* range from -1.00 to +1.00 (Benesty et al., 2009). The closer the coefficients are to -1.00 or +1.00, the greater the strength of the linear relationship is. The test of significance may show that the two methods are related however, this may be misleading. The significance of the correlation depends on the values of the correlation coefficient. If the *r* is statistically significant with respect to the set limit (such as $p < 0.005$) only then we can interpret its value. If $p < 0.005$ we cannot conclude that there is significant relationship but we can claim that there is no relationship between the variables because the calculated coefficient of variation, which indicates the absence of correlation, is statistically significant (Benesty et al., 2009).

A linear regression is performed together with correlation measurement. In actual fact linear regression can be calculated only if the correlation exists and correlation coefficient can be interpreted only if the *p* value is statistically significant (Mathebula et al., 2016). Linear regression finds the best line that predicts one variable from the other one, and quantifies goodness of fit with the coefficient of determination (r^2), Coefficient of determination (r^2) only tell us the proportion of variance that the two variables have in common.

The Pearson correlation was used to measure the correlations among pairs of *measurements* and to indicate if a statistically significant linear relationship exists between measurements Table 4 and figures 2-5 show that the correlations were 0.701, 0.669, 0.738 and 0.659, respectively. The table and the scatter plots show that there is a strong linear relationship among measurements. The magnitude or strength of the association was approximately ($0.738 < r > 0.659$). Coefficient of determination (r^2) shows the proportion variance that the two measurements have in common.

Coefficient of determination also denoted as r^2 demonstrate the proportion of the variability of y that can be attributed to its linear relation with *x*. It is interpreted as a percentage of the variability in *y* due to variation of *x*. Since the measurements were highly correlated, the simple linear regression was performed to predict the value of one (dependent) measurement from the value of the other (independent) by means of the linear regression equation. The straight line or regression line is the “line of best fit” for the measurement points on the scatter plot. The regression line has the general formula of $y = a+bx$, were *a* and *b* are two constants denoting the intercept of the line on the y-axis (y-intercept) and the gradient (slope) of the line, respectively.

Physically, *b* represents the change in *y* for every one unit change in *x*, while *a* represents the value that *y* will take if *x* is zero. Once the values of *a* and *b* have been established, the expected value of *y* can be predicted for any given value of *x*, and vice versa.

Table 4 Paired sample Pearson correlation coefficients for end point with duochrome and cross cylinder. The highest correlation is between the duochrome in bright and cross grid in dim illumination, while duochrome in dim and cross grid in bright illumination had the lowest correlation.

Combination	**Pearson correlation co-efficiency (*r*)**	**Statistical significance (*p*)**
Duochrome in bright/Cross grid in bright	0.701	0.000
Duochrome in dim/ cross grid in dim	0.669	0.000
Duochrome in bright/ cross grid in dim	0.738	0.000
Duochrome in dim and cross grid in bright	0.659	0.000

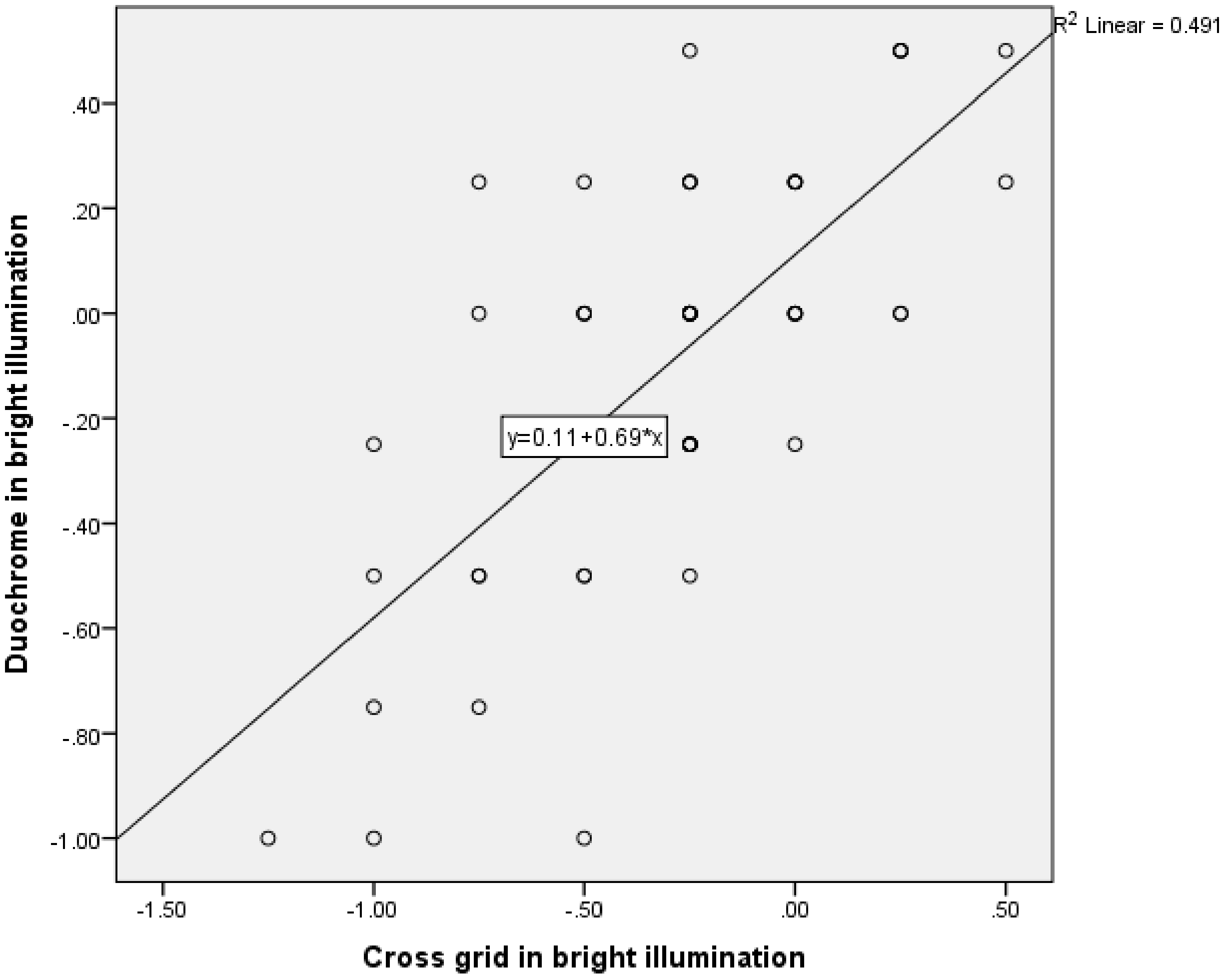


Figure 2 Correlation of the end point determined using the duochrome in bright illumination versus cross grid in bright illumination, r = 0.70.

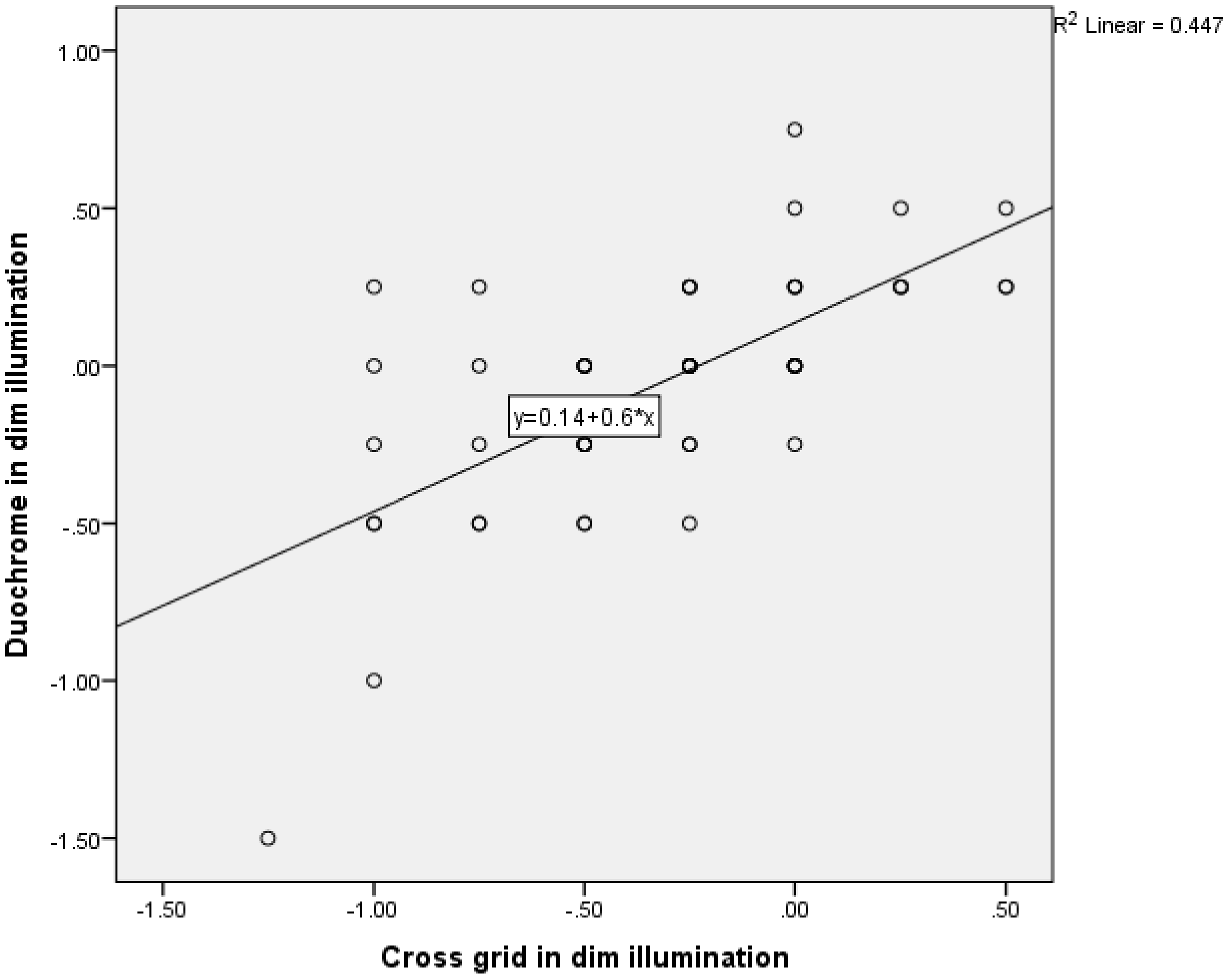


Figure 3. Correlation of the end point determined using the duochrome in dim illumination versus cross grid in dim illumination, r = 0.669.

*

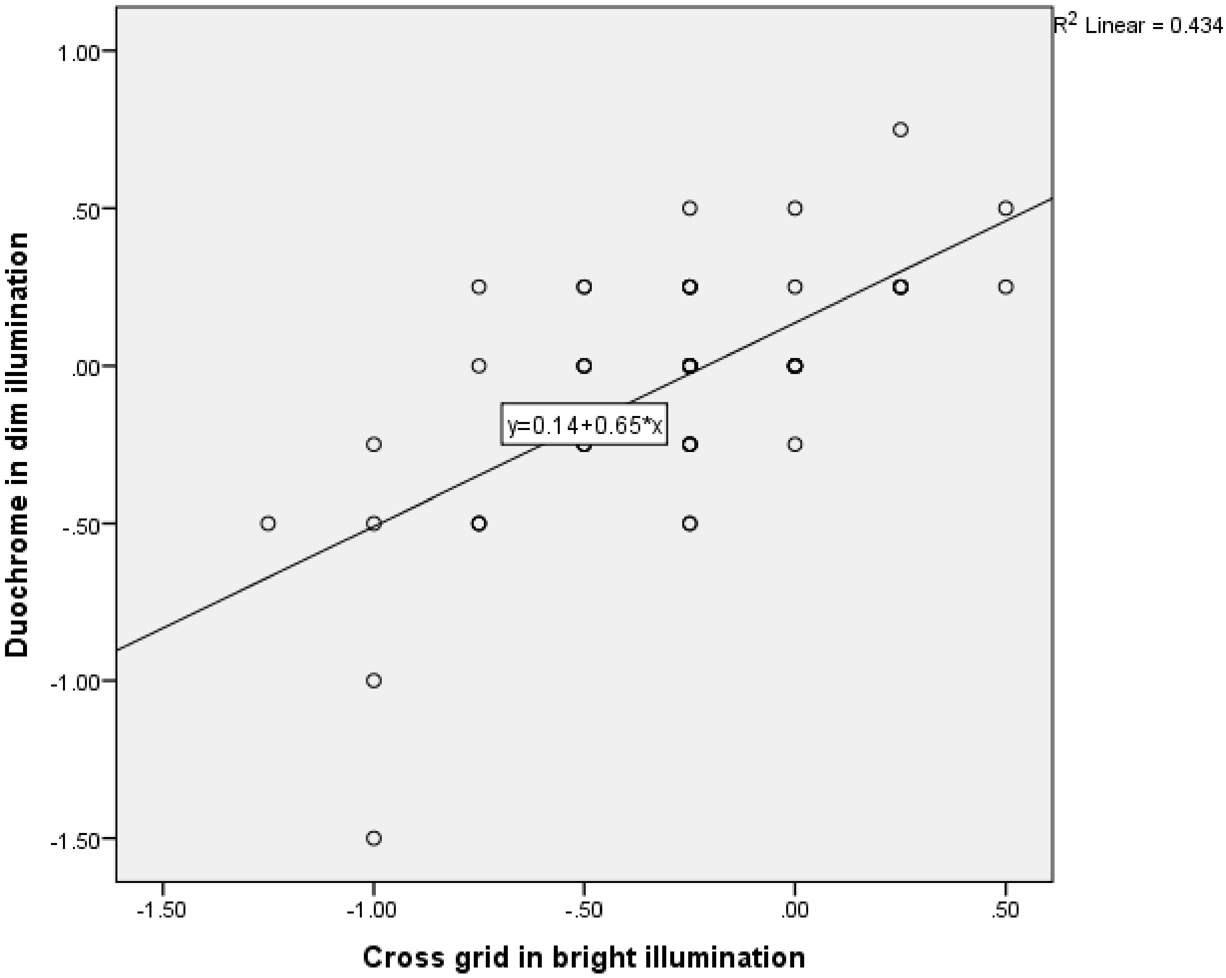


Figure 4. Correlation of the end point determined using the duochrome in dim illumination versus cross grid in bright illumination, r = 0.659.

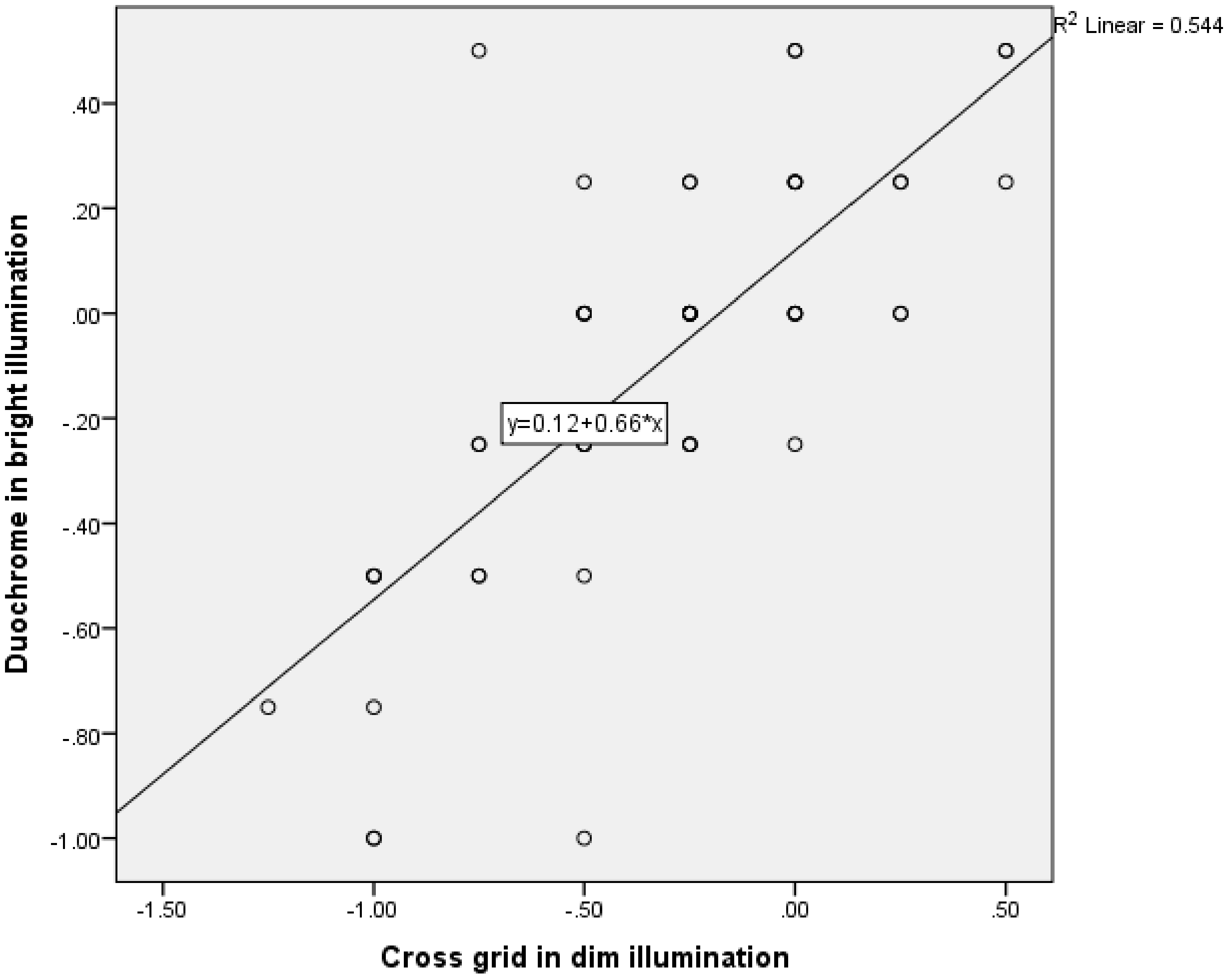


Figure 5. Correlation of the end point determined using the duochrome in bright illumination versus cross grid in dim illumination, r = 0.738.

The correlation analysis is not the most appropriate method to evaluate agreement between two tests. The test which supposedly measure the same quantity would be expected to show an association by correlation, but this correlation does not imply agreement. The test of significance may show that the two methods are related, however, this could be misleading. The Bland-Altman displays a scatter diagram of the mean differences plotted against the mean of two measurements (Carkeet, 2015). The average of the differences between measurements and using the mean of the measurements are used to determine the 95% limit of agreement and using the standard deviation of the differences. This method can be used for the comparison between the tests or in evaluation of test-retest reliability. Table 4 and Figures 4-7 represent the Bland-Altman (difference) plots. The differences between each pair of the monocular end points is plotted against the mean differences. Three horizontal lines are drawn. One is drawn at the mean difference and two at the limits of agreement, which are defined as the mean difference plus and minus 1.96 standard deviation of the differences. If 95% of the data points are within ±1.96 standard deviation, there is an agreement (Carkeet, 2015). The limits of agreement (LoA) are the interval of two standard deviations of the measurement differences either side of the mean difference. Thus, the upper limit of agreement is given by:

Upper limit of agreement = mean difference + 1.96 (standard deviation of differences),

Lower limit of agreement = mean difference -1.96 (standard deviation of the differences).

According to the Figures 4 and 5, there is a strong agreement between the measurements. However, Figure 6 and 7 show a skewed agreement. If the data is normally distributed, one would expect approximately 95% of the difference in the sample to lie within 1.96 ± SD from the mean difference, hence limits of agreements are often called 95% limits of agreement.

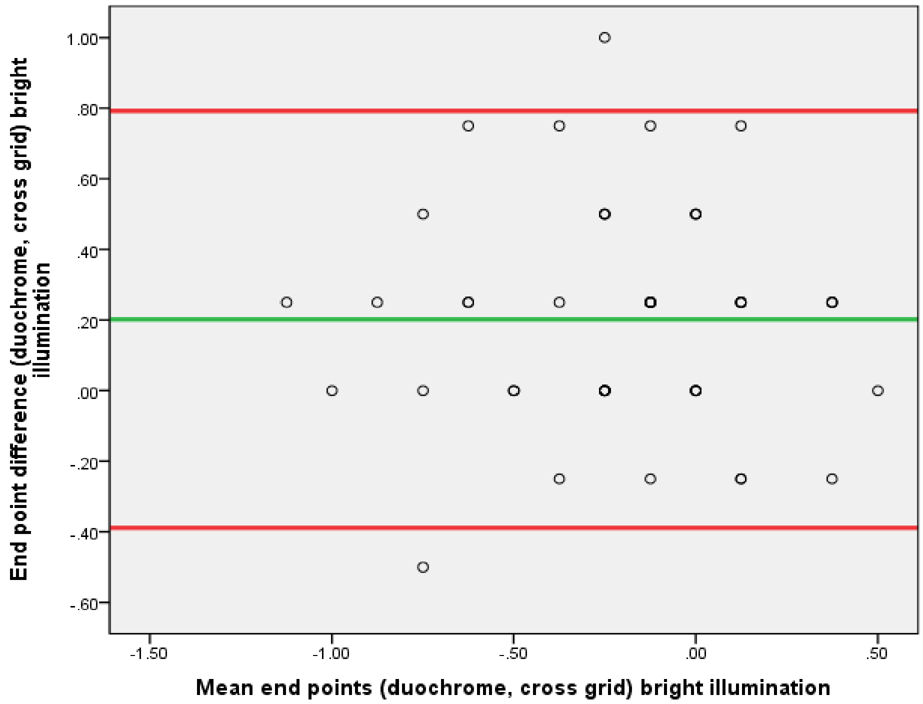
The limits of agreement are meant to be estimates of the range in the population which 95% of the differences between two measurements lie. Since the estimates of the LoAs are based on sample statistics they will be associated with some uncertainty, and thus should be accompanied by an estimate of confidence intervals on limits (Figures 4b, 5b, 6b, 7b). To calculate the confidence intervals for LoAs involves using the two-sided tolerance factors for a normal distribution. The confidence intervals closer to the mean difference (inner confidence interval) is calculated using coefficient 0.025 while for those outer confidence intervals furthest from the mean we use coefficient 0.975 using the coefficients for 95% LoAs of the *t* distribution.

Table 4 lists the mean differences, standard deviation and 95% LoA for any paired comparison of the four measurements. The highest mean difference was between duochrome in bright illumination and cross grid in dim illumination (0.240), and the weakest mean difference was between duochrome in bright illumination and duochrome in dim illumination (-0.385). Scatter plot of the mean difference was performed (see Figures 6c and 8c).

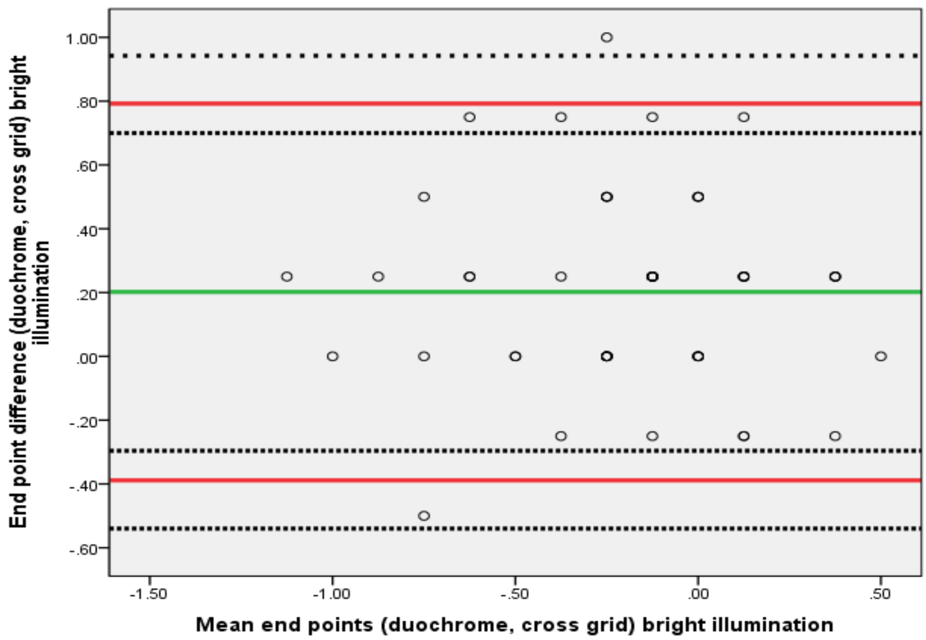
Table 4. Statistics for the confidence interval estimation of the mean differences

Statistics		**Mean difference A**	**Mean difference B**	**Mean difference C**	**Mean difference D**
Mean		0.2019	0.2260	-0.385	0.240
SD		0.30130	0.29811	0.27290	0.2855
95% CI	**Lower**	0.1180	0.1430	-0.1144	-0.554
	Upper	0.2858	0.3090	0.0375	0.1035
Minimum		-0.50	-0.50	-1.00	-0.75
Maximum		1.00	1.25	0.75	0.75

(a)


1.00
.80
.60
.40
.20
.00
-.20
-.40
-.60
-1.50
-1.00
-.50
.00
.50
End point difference (duochrome, cross grid) bright illumination
Mean end points (duochrome, cross grid) bright illumination

(b)


1.00
.80
.60
.40
.20
.00
-.20
-.40
-.60
-1.50
-1.00
-.50
.00
.50
End point difference (duochrome, cross grid) bright illumination
Mean end points (duochrome, cross grid) bright illumination

(c)

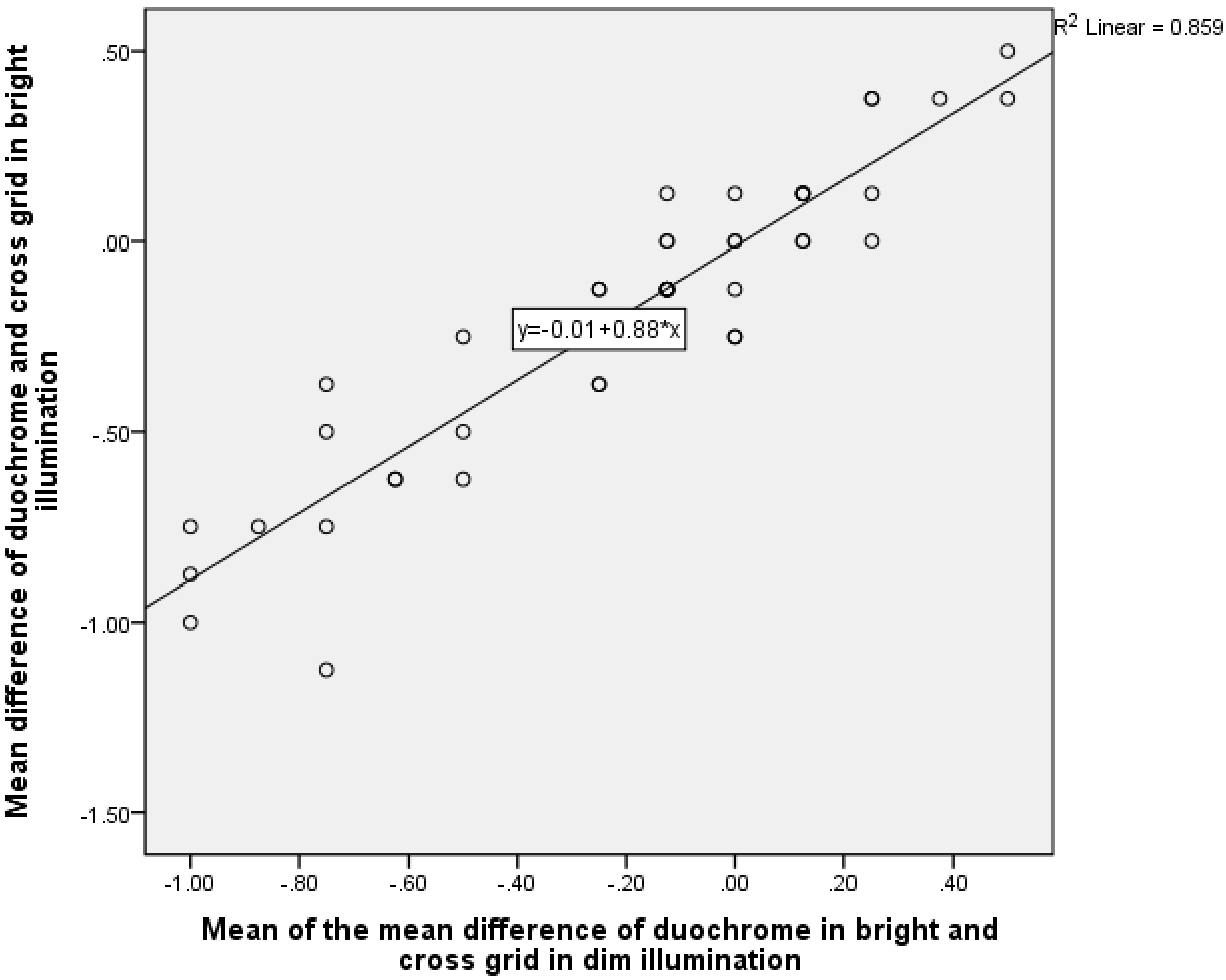
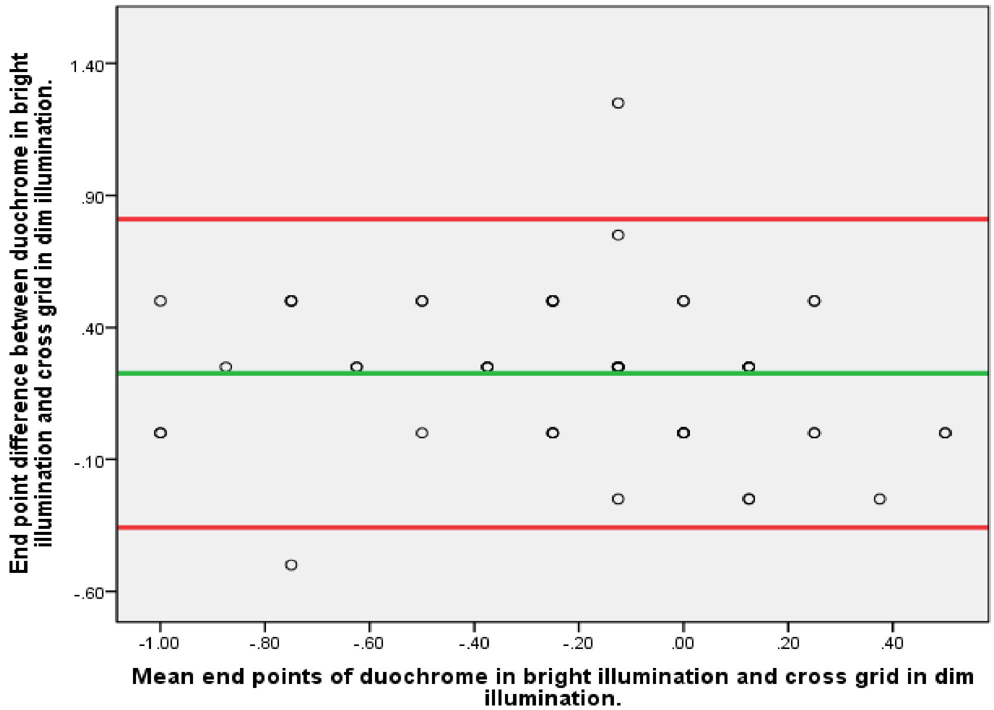


Figure 6. A Bland-Altman plot (a) and with confidence intervals (b) of the differences versus the means of duochrome and cross grid in bright illumination. The *y*-axis shows the difference between the two methods and the *x*-axis represents the mean of the two measurements. The red horizontal line indicates the mean difference between the two methods. While the two blue lines represent the 95% limit of agreement. The scatter plot of the mean difference is shown in (c).

(a)



(b)

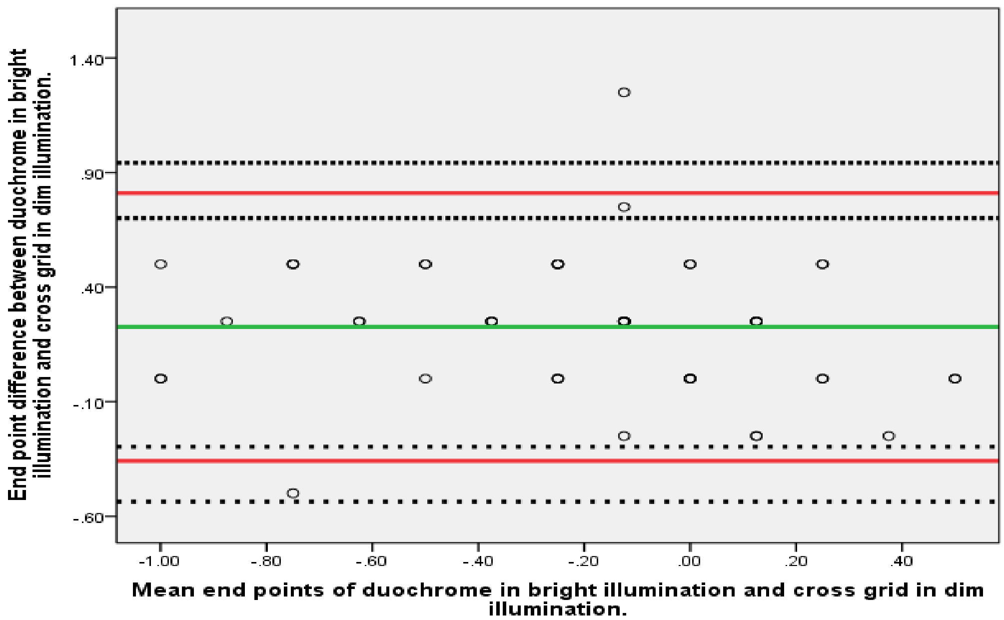
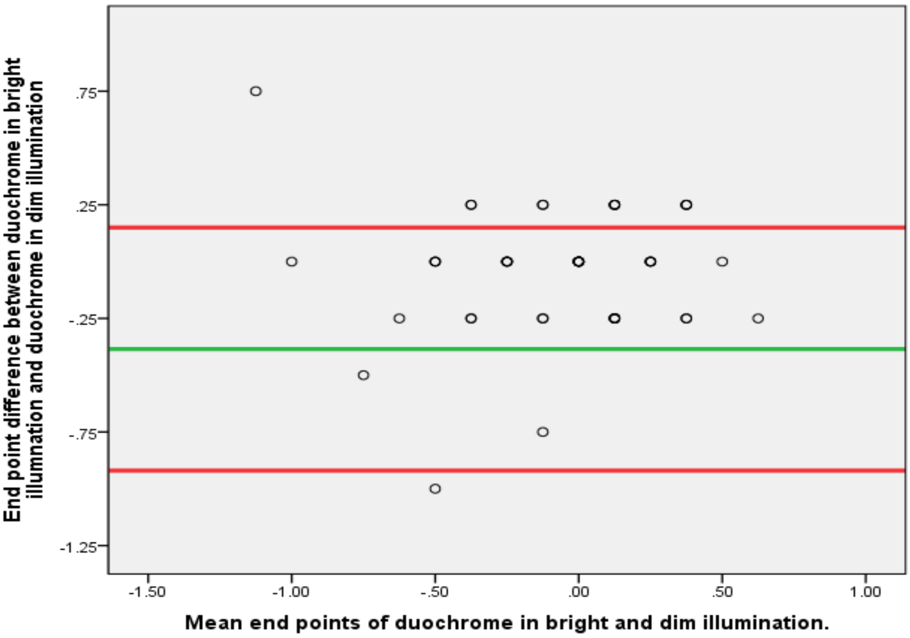


Figure 7. A Bland-Altman plot (a) and with confidence intervals (b) of the differences versus the means of duochrome and cross grid in dim illumination. The *y*-axis shows the difference between the two methods and the *x*-axis represents the mean of the two measurements. The

red horizontal line indicates the mean difference between the two methods. While the two blue lines represent the 95% limit of agreement.

(a)



(b)

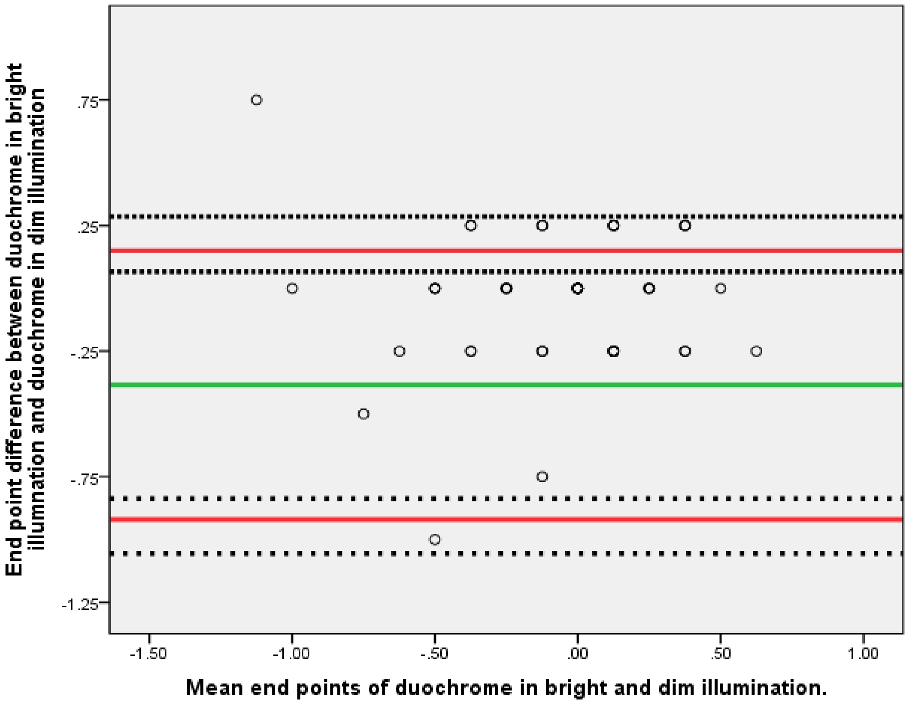
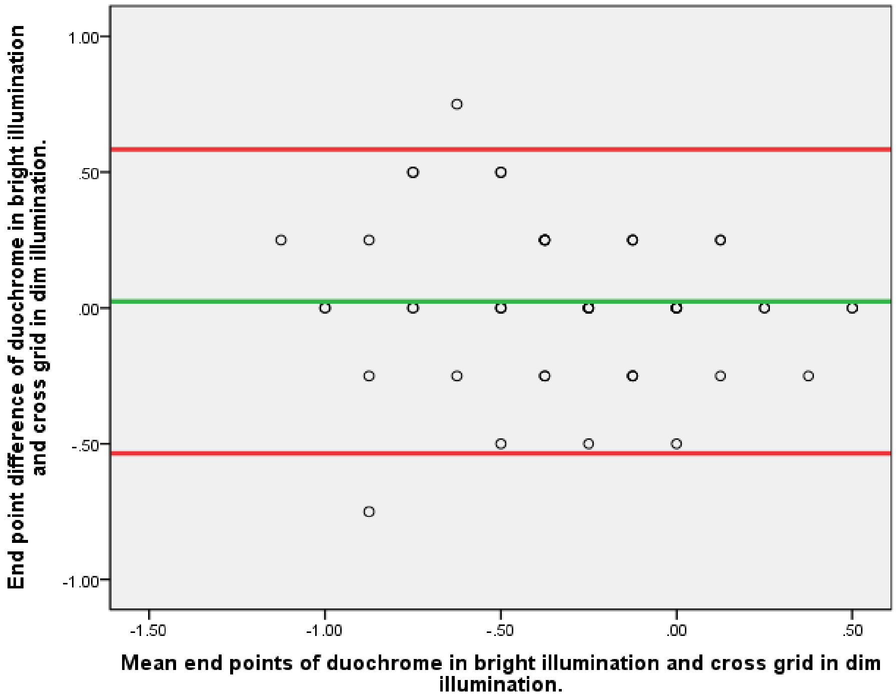


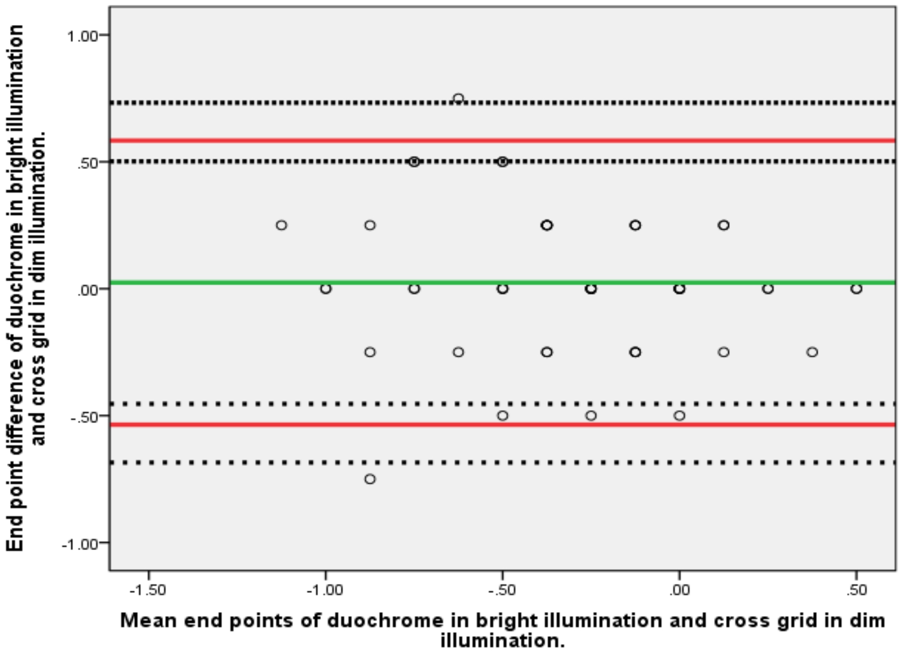
Figure 8. A Bland-Altman plot (a) and with confidence intervals (b) of the differences versus the means of duochrome in bright and dim illumination. The *y*-axis shows the difference between the two methods and the *x*-axis represents the mean of the two measurements. The

red horizontal line indicates the mean difference between the two methods. While the two blue lines represent the 95% limit of agreement.

(a)



(b)



(c)

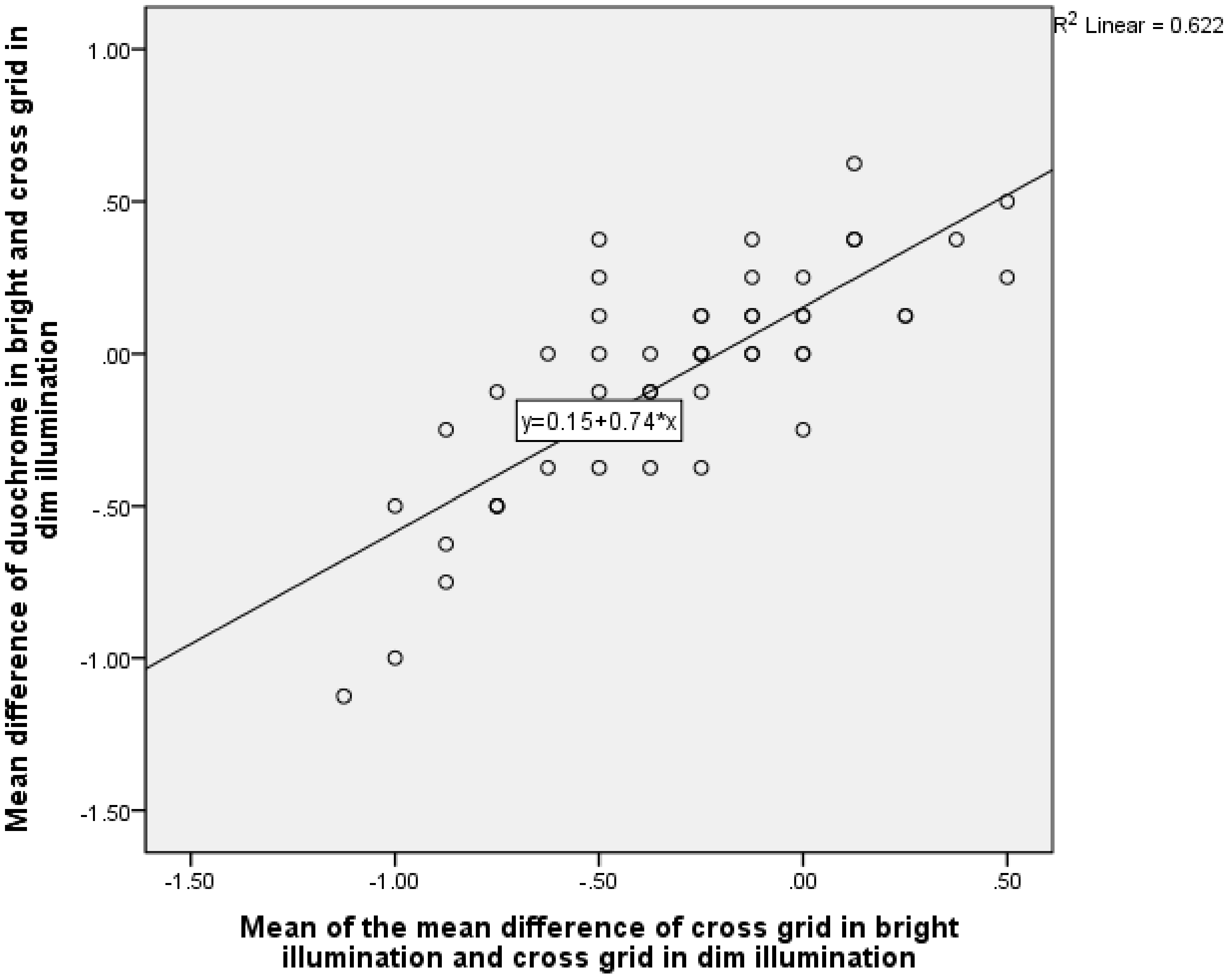


Figure 9. A Bland-Altman plot (a) and with confidence intervals (b) of the differences versus the means of duochrome in bright illumination and cross grid in dim illumination. The *y*-axis shows the difference between the two methods and the *x*-axis represents the mean of the two measurements. The red horizontal line indicates the mean difference between the two methods. While the two blue lines represent the 95% limit of agreement. The scatter plot of the mean difference is shown in (c).

CHAPTER FIVE

5. DISCUSSION

The purpose of the study was to investigate the use of the cross cylinder in conjunction with the cross grid as an alternative for the duochrome (bichrome) technique amongst University of Limpopo optometry students. The overriding determination of the monocular subjective end point is the ability of the patient to resolve the letters not so much about the clarity or distinctiveness of the letters (Grosvernor, 2007). As plus lens power were decreased (or minus lens power increased) in 0.25D at a time, the participant was asked to read aloud the letters downward from one line to the next. When an additional decrease in plus lens power did not make any more letters readable the previous lens power in the phoropter satisfied the criterion “maximum plus for best acuity”. Participants should not be allowed in terms of clarity of the letters or in terms of which the lens power is preferred as young patients will continue to accommodate with each 0.25D of the reduction in plus lens power, with result that the end point will be completely invalid (Grosvernor, 2007). When minus lens power was added to the point that accommodation was necessary to keep the letters in sharp focus on the retina, many participants noticed that the letters appeared to be smaller (accommodative micropsia).

The VA was measured for each participant, so that if there was a need for improvement, refraction could be performed and subsequently optical correction could be used to improve the VA. The distance uncorrected VA was found to range from -0.30 to 1.00 LogMAR for right eyes and subsequently from -0.30 to 1.00 LogMAR for the left eyes (Table 1). Similarly, for both eyes the VA ranged from -0.30 to 1.00 LogMAR (Table 1). The results of the current study are almost similar to the findings of Mohamed et al. (2015) who found the uncorrected visual acuities to range from 0.00 to 1.00 LogMAR for both the left and the right eyes amongst Assiut University students in Egypt.

Table 2 shows the descriptive statistics for the measurements of the refractive end points. Table 2(a) and Figure 1(a) show that the measurements had many outliers hence the higher negative skewness and larger kurtosis. Even though there were outliers, measurements were approximately normally distributed. Once the outliers were removed the skewness and kurtosis were reduced significantly and measurements were normally distributed, as seen in Figure 1(b). The shapes of the box plots were slightly elongated. The data without outliers were used to perform subsequent analysis.

The results show that the monocular end point using the duochrome is higher than when using the cross grid method (Table 2 and Figure 1b). However, the results of the duochrome and cross grid are nearly the same, both in dim and bright illumination respectively. The difference between duochrome and cross grid in bright illumination was 0.199 D, whilst in dim the difference is 0.258 D. Duochrome can be used either as a monocular end point test in which each eye is tested separately or as a binocular balancing test making use of either prism dissociation or alternate occlusion. It is commonly done in an almost completely darkened room (Mathebula, 2001; Momeni-Moghadan & Goss, 2014). The monocular and binocular cross cylinder test provide information about the posturing of accommodation at 40 cm and can be thought of as a near subjective test (Bennett, 2007). For this test, the test target is the cross cylinder grid and the illumination on the near point card must be very low. If illumination is too high the depth of focus will be great that it will make the results of the test meaningless (Grosvernor, 2007). Generally, the cross cylinder findings provide information concerning the lag of accommodation. In some cases, the cross cylinder findings identify patients who have latent hyperopia and high AC/A ratio or who could benefit from the prescription of additional plus lens power for near or multifocal lenses (Griffin & Grisham, 2002).

However, comparing means alone might yield erroneous results as both outliers and sample size might affect the outcome. The coefficient of correlation (*r*) measures the strength between two variables. It is possible that data obtained by two examiners using the same test conditions and procedures were not related. The correlation between duochrome and cross grid in both bright and dim illumination varied from 0.659 to 0.738. The highest correlation was between duochrome in bright and cross grid in dim (Table 3). The *p*- value is zero because we cannot claim that there is no relationship between the variables since the correlation is statistically significant (Mathebula et al., 2016). The regression analysis was performed and showed that there is a strong relationship between measurements obtained using the duochrome and cross grid (see Figures 2 to 5)

Duochrome is commonly done in dim room illumination, however, the results of this study show the test can be done in full room illumination (see Figure 1b). Currently the duochrome is commonly used as the monocular and binocular balancing technique of the spherical power. The cross grid is commonly used to test the status of accommodation and to determine the tentative add. Following a thorough literature search, we could not find a study that has compared the duochrome with the cross grid at distance. Our results show that the cross grid could be performed in bright and dim illuminations.

In its clinical application the cross grid is used in determining the near point correction and in investigation of other near point function (Bennett, 2007; Grosvernor, 2007). It can also be used as an end point clinical test, since it produces results similar to the duochrome test. However, there are several factors that might limit the use of the duochrome technique. They include out-of-focusness of the targets and the relative brightness of each background colour. When the duochrome test is performed in colour defective patients the red side of the test appear duller to protans and some patients who always prefer one colour give poor results with duochrome (Mathebula, 2001; Momeni-Moghaddam & Goss 2014). The various companies which manufacture duochrome test do not use the same filters for their background colours and thus their duochrome test differ somewhat in this respect (Mandell & Allen, 1960).

The Bland-Altman plot was determined to show the agreement between the duochrome and cross grid, and how close the measurements are to perfect agreement. In Bland-Altman analysis a scatter plot is constructed in which the difference between the paired measurements is plotted on y-axis and of the measures of the two methods on x-axis. The mean difference in values obtained with two methods is called the *bias* and is represented by a central horizontal line on the plot (Figure 6-9). The plot enabled the researcher to asses visually the bias, data scatter and the relationship between magnitude of difference and size of measurement. The results of this study show that there is an agreement between duochrome and cross grid in both illuminations (Figure 4-7).

In comparing the two techniques the means of the differences were similar, which suggests a good agreement among them (Table 4). However, in some cases agreement was only fair (Figures 5 and 6), so that caution is recommended when using the results of the duochrome and cross grid interchangeably. Any conclusion on agreement and interchangeability of the two methods must be made based upon the width of the limit of agreement. Agreements is not just something which is merely present or absent but something which must be quantified. It simply quantifies the bias and a range of agreement, within which 95% of the difference between one measurement and the other are included. Only clinical goals could define whether the agreement interval is too wide or sufficiently narrow for the purpose, hence the use of the Bland-Altman plot system was defined prior the limits of maximum acceptable difference based on clinical relevance. The duochrome was regarded as the standard method and to define the limits of the interval. If the line of the bias and the wide spread of the measurements are not in the interval there is a significant systemic difference, that is the cross grid technique constantly under or overestimate the results of the duochrome technique.

5.1 Limitations of the study

There are several limitations of this study. Firstly, the results are based on a relatively small number of eyes. Secondly, this study is limited to young and healthy participants with normal and good fixation, the understanding of these participants regarding the techniques peformed was very good. In symptomatic and older patients with eye disease the results may be different and could include additional variability. Further review is required to comprehensively assess the validity of the cross grid technique at distance.

5.2 Conclusion

Clinical studies often need to assess the agreement between measurement methods. Every time we have to change one method for another or evaluate a new or alternative method, we need to measure and appreciate the differences as well as the causes of these differences. Based on a value of 0.5D for the 95% LOAs for the end points method of refraction, the duochrome and the cross grid yielded results which can be considered interchangeable. Our results show that the refractive end point measurements obtained from duochrome and cross grid are well correlated and comparable, suggesting that they could be used interchangeably in most clinical setting. However, caution is needed when using measurements obtained by cross grid in dim illumination.

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ANNEXURES

Annexure A (TREC APPROVAL)

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TURFLOOP RESEARCH ETHICS COMMITTEE CLEARANCE CERTIFICATE

MEETING:	**05 July 2016**
PROJECT NUMBER:	**TREC/52/2016: PG**

PROJECT:

Title:	A study to determine the use of cross cylinder in conjunction with cross grid at distance as an alternative method for the Douchrome Technique amongst University of Limpopo Optometry students
Researcher:	Mr NT Makgaba
Supervisor:	Prof SD Mathebula
Co-Supervisor:	Mr PMW Nkoana
Department:	Medical Sciences, Public Health and Health Promotion
School:	Health Care Science
Degree:	Masters in Optometry

PROF TAB MASHEGO
CHAIRPERSON: TURFLOOP RESEARCH ETHICS COMMITTEE

The Turfloop Research Ethics Committee (TREC) is registered with the National Health Research Ethics Council, Registration Number: **REC-0310111-031**

Note:
i) **Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee.**
ii) **The budget for the research will be considered separately from the protocol.**
PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.

Finding solutions for Africa

Annexure B (Consent form)

UNIVERSITY OF THE LIMPOPO

ETHICS COMMITTEE

PROJECT TITLE: **A study to determine the use of cross cylinder in conjunction with cross grid at distance as an alternative method for the duochrome technique, amongst University of Limpopo optometry students.**

PROJECT LEADER: PROF. SD MATHEBULA

CONSENT FORM

I, ____ hereby voluntarily consent to participate in the following project: **A study to determine the use of cross cylinder at distance as an alternative for the duochrome technique.**

I realize that:

1. The study deals with eye examination and assessment of the refractive and accommodative status of the participants.

2. The procedure or 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 experimental 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 participating in the research, an explanation of the anticipated advantages for myself or others that are reasonably expected from the research and alternative procedures that may be to my advantage;

6. I will be informed of any new information that may become available during the research that may influence my willingness to continue my participation;

7. Access to the records that pertain to my participation in the study will be restricted to persons directly involved in the research;

8. Any questions that I may have regarding the research, or related matters, will be answered by the researchers;

9. If I have any questions about, or problems regarding the study, or experience any undesirable effects, I may contact a member of the research team;

10. Participation in this research is voluntary and I can withdraw my participation at any stage;

11. If any medical problem is identified at any stage during the research, 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 project from any liability that may arise from my participation in the above project or that may be related to it, for whatever reasons, including negligence on the part of the mentioned persons.

SIGNATURE OF PARTICIPANT SIGNATURE OF WITNESS

SIGNATURE OF PERSON THAT INFORMED THE PARTICIPANT

SIGNATURE OF PARENT/GUARDIAN

Signed at ________________________________this ____day of _________________2016

Annexure C (Data collecting tool)

Serial Number		Age
Visual Acuity		
Right Eye	***Left Eye***	***Both Eyes***
Colour Vision		
Right Eye	***Left Eye***	
Subjective refraction		
Right Eye	***Left Eye***	
Duochrome (Bright Illumination)		
Right Eye	***Left Eye***	
Duochrome (Dim Illumination)		
Right Eye	***Left Eye***	
Distance cross cyl and Cross grid (Bright Illumination)		
Right Eye	***Left Eye***	
Distance cross cyl and Cross grid (Dim Illumination)		
Right Eye	***Left Eye***	

Annexure D (Budget)

Item	Cost	Total
Cross grid projector	R15000.00	R15000.00
Trial Lens set	R5000.00	R5000.00
Ishihara Test Plates	R4000.00	R4000.00
Trial Frame	R2000.00	R2000.00
Printing cartridge	R500/ cartridge	R500.00
Binding	R250 x4	R1000.00
Grand Total		R27500.00