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Investigation of the unfused cross cylinder test as an alternative method for the determination of spherical distance refraction end points

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Background: The duochrome test is commonly used to refine the final sphere in refraction at different stages of a subjective refraction. The unfused cross cylinder test is mainly used to determine the near reading addition with a combination of astigmatic lenses.

Aim: To investigate if the unfused cross cylinder test can be adapted for distance in finding the spherical end point for distance prescription.

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

Methods: Fifty-one non-presbyopic subjects aged between 18 and 25 years were examined. The duochrome and unfused cross cylinder examinations were performed monocularly under normal (bright) and dim room illumination.

Results: There was no significant difference in the spherical end point determined with either the duochrome or unfused cross cylinder tests ($p \geq 0.05$). The mean spherical end points as determined with the duochrome test were −0.09 ± 0.39 diopre sphere (DS) (range: −0.20 to 0.12 dioptres [D]) in bright room illumination and −0.05 ± 0.38 DS (range: −0.16 D to 0.05 D) in dim illumination. The mean spherical end points for the unfused cross cylinder tests were −0.29 ± 0.39 DS (range: −0.18 D to 0.40 D) and −0.32 ± 0.43 DS (range: –0.44 D to –0.19 D) in room dim illuminations, respectively.

Conclusion: The unfused cross cylinder test results as performed in this study may provide an accurate measurement of the spherical end point in a young adult population. We recommend the unfused cross cylinder test to be used in normal (bright) room illumination as an alternative to the duochrome test in the determination of distance refractive error.

Keywords: duochrome; bichrome; unfused cross cylinder; spherical end point; chromatic aberration.

Introduction

The red–green duochrome (bichrome) test is based on the principles of axial chromatic aberration. The eye, like most common optical systems, displays a certain amount of axial chromatic aberration.[1,2,3,4,5,6,7,8] A yellow wavelength of approximately 570 nanometres (nm) is preferred by the eye.[3,6] The red and green wavelengths are dioptrically equidistant from the yellow wavelength.[3,6] Green light with a wavelength of 535 nm focuses 0.25 dioptres (D) in front of the retina, and red light with a wavelength of 620 nm focuses 0.25 D behind it.[8] This is because the shorter wavelength (green) is refracted more by the eye's optics than the longer wavelength (red).

The duochrome test under monocular conditions is used to compare the clarity of targets presented on red and green backgrounds because it allows the clinician to focus the yellow reference wavelength accurately on the retina.[4] The best visual acuity or vision is only attained when the yellow wavelength light from a distant object focuses on the retina in an eye that is properly compensated to be emmetropic and will see the black letters, numbers, dots, circles or symbols on both the red and green backgrounds having equal clarity.[3] Once the black targets appear equally clear to the patient, the red and green foci are dioptrically equal on either side of the retina as a result of the 0.50-D interval between the eye's powers for the two colours.[6]

The cross cylinder technique was introduced by Jackson in 1887 and later in 1907 to determine the cylinder axis and the cylinder power;[9,10,11,12] hence, it is called the Jackson cross cylinder (JCC).

The cross cylinder is an astigmatic lens in which the two principal powers are numerically equal but opposite in sign; thus, the mean power is zero. The lens is marked with a position of the axes, plus or minus signs or with coloured dots, in which + is usually red and – is usually white or black. The monocular (unfused) and binocular (fused) cross cylinder findings at 40 cm provide the clinician with information about the posturing of accommodation.[3,4,13,14,15,16] Although the cross cylinder test is mainly used to determine the near addition, some phoropter projectors come with a cross grid chart for distance viewing; hence, it can be used to determine the end point of distance prescription.

To our knowledge, no previous study has compared the duochrome and cross cylinder findings at 6 m. The duochrome test has a number of factors that can affect the end point results obtained. Thus, the purpose of this study was to investigate the possibility of using the unfused cross cylinder test at distance as an alternative method to the duochrome technique.

Methods

Fifty-one participants with an average age of 20.6 ± 1.8 years (18–25 years of age; 27 females and 25 males; median age: 21 years) were recruited to participate in the study. Each participant provided written informed consent, and the study was conducted in adherence to the principles of the Declaration of Helsinki on human subjects. Participants were included in the study if they had corrected or uncorrected (uncompensated) visual acuity of 6/6 or better in each eye, no strabismus, no colour defect and no reported history of ocular disease or refractive surgery.

Procedures

The monocular duochrome test was performed both in a normally illuminated room and a completely darkened room; however, the projector screen was in virtual darkness except for light from the projector (PLC-8000, Potec Co., Ltd., Korea). Starting with the monocular best sphere results, 0.5 D of spherical power was added. The test was performed monocularly. The right eye was tested first, whilst the left eye was occluded. The duochrome image was projected using a standard screen projector on the screen at 6 m. Subjects were then instructed to concentrate on the black numbers on the green half of the screen, compare them with those on the red half and report which background provided clearer and sharper numbers. On the phoropter there was no filter placed except projected image. The subjects were asked to report which of the numbers were sharper, blacker or more distinct – those on the red background or those on the green background. When the original monocular subjective end point was correct, the subjects reported that the target on red background were more distinct with +0.25 D and +0.50 D of fog. However, when all fog was removed, the targets appeared equally distinct on both the red and green sides. When an additional +0.25 D of lens power was removed from the subjective refraction, the target on the green background appeared to be more distinct. The end point criterion was the lens power at which the targets on red and green backgrounds appeared to be equally distinct. However, some participants' responses changed from red to green or from green to red with a 0.25 D change in power, and the target on red background was taken as the end point.

Because the subjects were not presbyopic, the cross cylinder test was first used to check the distance correction. Each subject was first asked to observe the cross grid without the cross cylinder and to report immediately if the up and down (vertical) or across (horizontal) lines appeared clearer. An immediate response was required because cross cylinder left in place for length of time may bring one meridian of the test object into focus, and the eye may accommodate to make the vertical lines clearer but be unable to relax to make the horizontal lines clearer.[14]

The unfused cross cylinder test was performed without the use of additional fogging lenses. Cross cylinders of ±0.25 D with minus vertical axes vertically oriented were introduced before each eye. Participants were required to view a conventional cross grid target projected at a viewing distance of 6 m. They were asked to observe the cross grid without the cross cylinder and to report immediately if the horizontal or vertical lines appeared sharper. Then, the ±0.25 D cross cylinder was added. The target was viewed through the subjective refraction result on the phoropter. Participants were then asked to indicate whether the horizontal or vertical lines appeared either clearer or darker. At the start of the test, the lines going across were more distinct. Lens power was then added in +0.25 D increments until the participants reported that the vertical and horizontal lines of the cross grid were equally distinct. When the reversal occurred directly from horizontal to vertical lines with no report of equally distinct, the findings were recorded as the least plus through which the vertical lines were more distinct than the across lines. Once the test was completed for the right eye, the researcher occluded it and opened the left eye.

Data analysis

Data analysis was performed using the Statistical Package for Social Sciences (SPSS) version 24 (SPSS, Inc., Chicago, IL, the United States of America). The significance level was considered as $p < 0.05$ in all tests. Paired t-tests and a Bland–Altman plot[17,18] were used to assess the level of agreement between the duochrome and unfused cross cylinder tests. Because the right and left eyes of a sample are significantly correlated ($r = 0.90$, $p < 0.05$), data for the right eyes of the subjects were analysed to avoid the confounding effect of using non-independent data from both eyes.[19] Because measurements from the right and left eyes are very similar, the left eye measurements would add little or no information.

Ethical consideration

Ethical approval to conduct the study was obtained from the University of Limpopo (Clearance No. TREC/52/2016:PG).

Results

Table 1 and Figure 1 show the descriptive and graphical analysis for the duochrome and unfused cross cylinder measurements. The results of skewness and kurtosis are also presented. The mean end points with their standard deviations (s.d.) for duochrome in bright −0.09 ± 0.39 D, unfused cross cylinder in bright −0.05 ± 0.38 D, and duochrome in dim illumination −0.29 ± 0.39 D and unfused cross cylinder in dim illumination −0.32 ± 0.43 D. The 95% confidence intervals (CIs) are also presented for the mean end points. Figure 1 shows more variation of measurements in dim illumination.

Figures 2 and 3 show the Bland–Altman plots for the differences against the means for each comparison. The plots are the means of the two measurements versus their difference. Horizontal lines are drawn at the mean difference, whilst the 95% limits of agreement (LoA) are presented by the upper and lower lines. The upper and lower LoA are equal to the mean difference ± 1.96 × s.d. The mean differences between the duochrome and cross cylinder measurements were generally positive but low values (< 0.26 D). The largest mean difference was seen between the duochrome and unfused cross cylinder tests when both methods were performed in dim room illumination or darkness. There was no significant difference between the duochrome and cross cylinder tests in bright and dim illumination ($p > 0.05$).

The intraclass correlation coefficients (ICCs) and their 95% CIs were determined to assess the reliability of the duochrome and unfused cross cylinder end points (see Table 3). The ICC values were computed and differentiated according to the conditions of illumination and the methods. The ICC values ranged between 0.66 and 0.76, whilst the alpha values ranged between 0.8 and 0.9. The estimated reliability between the duochrome and unfused cross cylinder measurements was 0.71, with a 95% CI of 0.6–0.8, which is quite wide. The ICC values ranged between 0.6 and 0.8, meaning that there is a 71.2% chance that the true ICC value is between 0.6 and 0.8, The *single measure* is the estimated reliability between measurements.[17] The *average measure* is the Cronbach's alpha, which is a coefficient of reliability or internal consistency that measures how closely

TABLE 1: Descriptive statistics for the duochrome and unfused cross cylinder tests in dioptres.

Statistic	Duochrome		Cross cylinder	
	Bright light	Dim light	Bright light	Dim light
Mean ± s.d.	−0.09 ± 0.39	−0.05 ± 0.38	−0.29 ± 0.39	−0.32 ± 0.43
95% CI	0.02	0.05	−0.18	−0.19
	−0.20	−0.16	0.40	−0.44
Median	0.00	0.00	−0.25	−0.25
Skewness	−0.64	−1.14	−0.30	−0.12
Kurtosis	0.11	3.16	−0.05	−0.50
IQR				
25	−0.25	−0.25	−0.50	−0.50
50	0.00	0.00	−0.25	−0.25
75	0.25	0.25	0.00	0.00

s.d., standard deviation; CI, confidence interval; IQR, interquartile range

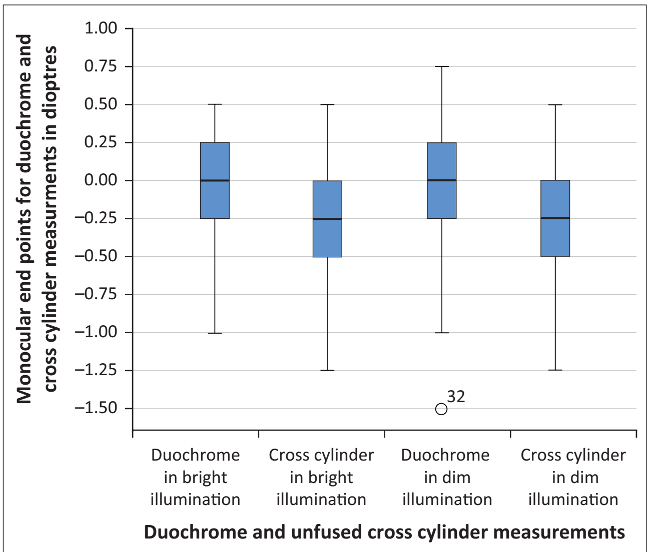

FIGURE 1: Box plot for the measurements of the duochrome and unfused cross cylinder tests for the right eyes. The boxes show the median and the first and third quartiles. The whiskers represent the range of the measurements.

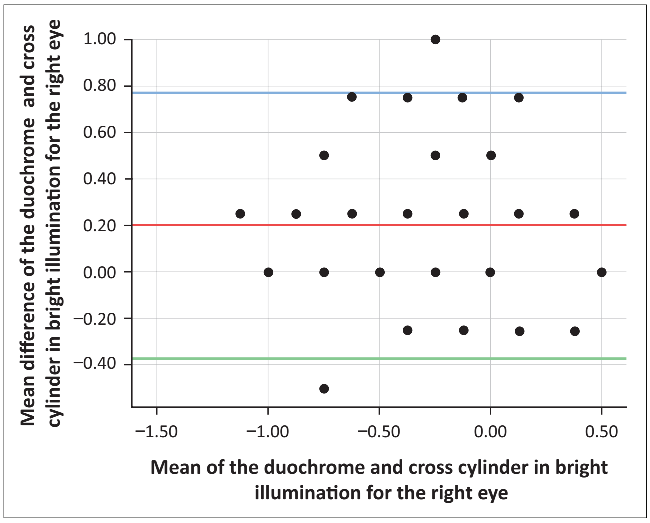

FIGURE 2: Plot of the means and differences ($\overline{D}$) between the duochrome and unfused cross cylinder tests in bright room illumination. The horizontal solid line represents the mean of the difference. The area between the two outer horizontal lines represents the 95% limits of agreement between the two methods.

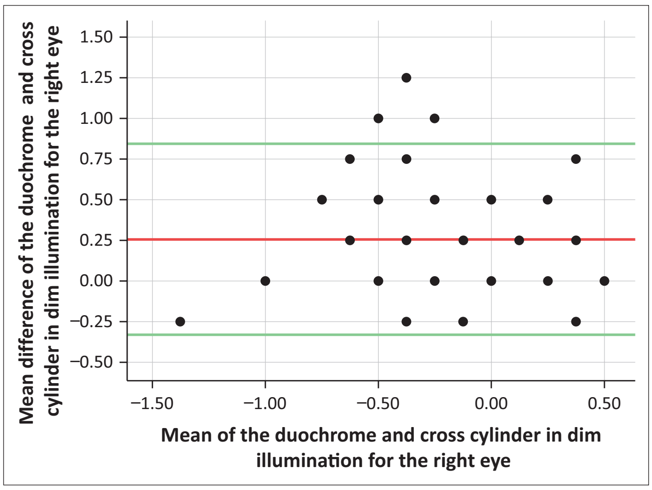

FIGURE 3: Plot of the means and differences between the duochrome and unfused cross cylinder tests in dim illumination.

related measurements are as a group. The Cronbach's alpha was 0.9, suggesting that the measurement end points have relatively high internal consistency.

The ICC is a number of correlation within a class of measurements with a value between 0 and 1, rather than the correlation between two different sets of measurements. It indicates similarities between values from the same group of measurements. A high ICC indicates high similarity, whilst a low ICC means measurements from the same group are not similar. The ICC will never be negative, unless the variability within the group of measurements exceeds the variable across the group of measurements.

The ICC is different from the Pearson correlation coefficient in that the measurements are centred and scaled using a pooled mean and standard deviation, whilst in the Pearson correlation each measurement is centred and scaled by its own mean and standard deviation. The ICC value obtained for the duochrome and cross cylinder tests in dim illumination was 0.67. It was not considered good enough for the intended use of the cross cylinder test as an end point for spherical measurements. An *F* test indicates whether the null hypothesis should be rejected, that is, it indicates absence of bias. Because the null hypothesis was not rejected, the ICC values were reported, together with their confidence intervals.

Discussion

The duochrome test is a test for refining the spherical component of the subjective refraction, when the astigmatism is corrected, if there is any.[8] It was designed and described by Clifford Brown in 1927 and later re-introduced by Freeman[20] in 1955. *Duochrome* means 'two colours' (*duo* = two, *chrome* = colour). It is derived from the fact that the test consists of black targets on a red and green background; hence, an alternative name for the test is 'bichromatic test'. This test involves comparing the focus of the black targets and not the brightness of the coloured backgrounds.

Based on the duochrome and the unfused cross cylinder methods, this study was undertaken to assess a novel method of determining the end point for non-presbyopia by using an unfused cross cylinder as an alternative to the duochrome test, which to our knowledge had not been studied previously.

The results of the study show that the mean difference (*bias*) between the duochrome and unfused cross cylinder tests in bright illumination was 0.20 ± 0.30 D (90% CI: 0.12–0.28 D). Moreover, the mean difference between the duochrome in bright illumination and the cross cylinder in darkness was 0.23 ± 0.30 D (95% CI: 0.14–0.32 D), which is similar to the mean difference when the tests were performed in bright illumination (see Table 2). The mean differences between the duochrome and cross cylinder tests performed in bright versus dim illumination were very small (0.04 ± 0.27 D and 0.02 ± 0.30 D, respectively). The linear regression analysis indicated a significant correlation between the duochrome and unfused cross cylinder findings ($p < 0.05$ with r ranging from 0.70 to 0.76).

TABLE 2: Mean differences ($\overline{D}$ or *Xd*), 95% confidence intervals and correlation between the duochrome and unfused cross cylinder tests.

Paired measurements	$\overline{D}$ ± s.d.	95% CI	*r*	*p*
Duochrome in bright illumination and cross cylinder in bright illumination	0.20 ± 0.30	0.12 to 0.28	0.70	0.00
Duochrome in bright illumination and duochrome in dim illumination	−0.04 ± 0.27	−0.11 to 0.37	0.75	0.30
Duochrome in bright illumination and cross cylinder in dim illumination	0.23 ± 0.30	0.14 to 0.31	0.74	0.00
Cross cylinder in bright illumination and cross cylinder in dim illumination	0.02 ± 0.30	−0.06 to 0.10	0.76	0.55
Duochrome in dim illumination and cross cylinder in dim illumination	0.26 ± 0.33	0.17 to 0.36	0.67	0.00

The units are in dioptres (*D*).
s.d., standard deviation; CI, confidence interval.

The unfused cross cylinder test was conducted in an unconventional clinical procedure because the room was not darkened by switching off the overhead lamp. One limitation of this study was that we could not control the level of room illumination. Although duochrome is the preferred test to check the final spherical end points, there are a number of factors that may affect the end point results obtained.[1,7,21] Not all duochrome tests use the same reference peak wavelength of 570 nm, so the dioptric interval of 0.50 D may vary a little from test to test, and the relative brightness of the red and green panels may also affect the end points.[3] The duochrome was illuminated by tungsten lamps, so the inappropriate light source may have influenced the results. The duochrome test is very quick and easy to perform; however, older or colour-defective patients tend to prefer red, which can provide unreliable duochrome results.[21] Darkening the room when performing the duochrome may cause the pupil to dilate and slightly increase the chromatic aberration of the eye, and the veiling glare may be reduced somewhat.

Reliability is defined as how well a test measures what it is intended for. The ICC is a useful estimator of reliability for quantitative data, or reliability index.[22] Before any measurement instruments or tools can be used for clinical or research application, their reliability should be established. The reliability value ranges between 0 and 1, with values closer to 1 representing stronger reliability.[22] The calculated ICC in this study was 0.71, which means that there is a 71.2% chance that the true ICC value will land on any point between 0.6 and 0.8. Therefore, the level of reliability in this study was moderate to good. Intraclass correlation coefficient values less than 0.5 are indicative of poor reliability, values between 0.50 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.

The Cronbach's alpha is a coefficient of reliability,[23] indicated as an average measure in Table 3. The alpha coefficient was 0.91 in this study, suggesting that the measurement tests have relatively high internal consistency.

TABLE 3: Results of intraclass correlation coefficient calculations in Statistical Package for Social Sciences using a two-way mixed model and consistency.

Procedure	Measure	Intraclass correlation	95% CI		F test with true value 0			
			Lower bound	Upper bound	Value	df1	df2	Sig.
Measurements done in room illumination	Single measure	0.70	0.53	0.82	5.68	51	51	0.00
	Average measure	0.82	0.69	0.90	5.68	51	51	0.00
Measurements done in dim illumination	Single measure	0.67	0.48	0.79	4.97	51	51	0.00
	Average measure	0.80	0.65	0.88	4.97	51	51	0.00

CI, confidence interval; *df,* degree of freedom; Sig., significance.

Calculating the alpha coefficient has become a common practice in research. There are different reports about the acceptable values for alpha, ranging from 0.70 to 0.90.[24,25,26] If the alpha value exceeds 0.90, then the instrument can be used on an individual patient in clinical practice; however, if it is less than 0.90 but exceeds 0.70, then it can distinguish amongst groups of patients in research. Other researchers have recommended that the lower limit of the ICC 95% CI should be at least 0.75.[24]

Conclusion

The findings of this study showed that there was no statistical difference between the results obtained using the duochrome and unfused cross cylinder methods. Thus, it appears that the unfused cross cylinder method may give reasonable results similar to the duochrome method. The results showed close agreement based on a value of less than 0.25 D for the 95% LoA. The unfused cross cylinder method could be used as a tool to determine the monocular end points or to counter the disadvantages of the duochrome method in the subjective refraction.

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Competing interests

The authors have declared that no competing interests exist.

Authors' contributions

N.T.M. collected the data and wrote the draft article. S.D.M. preformed the analysis and proofread the article. Both authors agreed to submit the manuscript for publication.

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Data availability statement

Data sharing is not applicable to this article.

Disclaimer

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