African Vision and Eye Health
ISSN: (Online) 2410-1516, (Print) 2413-3183

Inter-examiner repeatability and validity of static retinoscopy

Author:
Nabeela Hasrod[1]

Affiliation:
[1]Department of Optometry, Faculty of Health Sciences, University of Johannesburg, Johannesburg, South Africa

Corresponding author:
Nabeela Hasrod,
nabeelah@uj.ac.za

Dates:
Received: 27 July 2024
Accepted: 01 Nov. 2024
Published: 12 Feb. 2025

How to cite this article:
Hasrod N. Inter-examiner repeatability and validity of static retinoscopy. Afr Vision Eye Health. 2025;84(1), a982. https://doi.org/10.4102/aveh.v84i1.982

Background: Studies on inter-examiner repeatability of measurements from retinoscopy without cycloplegia are quite limited within and across individuals.

Aim: To investigate the inter-examiner repeatability and validity of static retinoscopy to autorefraction in young adults.

Setting: The study took place within a South African university.

Methods: Convenience, non-random sampling was used to obtain a sample of 68 adult participants, predominantly male (51.5%) of African descent (60.3%). The age range was from 18 years to 25 years with the mean ± standard deviation (s.d.) of 22.5 ± 0.71 years. The right eyes of participants underwent autorefraction, and static retinoscopy was done by two different student examiners. Bland-Altman plots and multivariate analysis were applied to assess inter-examiner repeatability and validity of retinoscopy to autorefraction of sphere, cylinder, spherical equivalent refraction (SER = M), and vector components J_0 and J_{45}.

Results: Stereo-pair scatter plots for the three refractive samples from both student examiners obtained for the right eye clustered within the same region, which suggested minimal variation in refractive error between the different samples. Bland-Altman plots for mean differences ($\overline{X}_d$) were less than or equal to one clinical step (0.25 dioptre [D]) for all refractive error variables although 95% Limits of Agreement (LoA) widths were larger for the spherical equivalent coefficients (M).

Conclusion: Clinically, inter-examiner retinoscopy is repeatable and comparable to autorefraction as results differed only by approximately 0.25 D.

Contribution: This study will be the first in Africa to provide multivariate analysis for inter-examiner repeatability of retinoscopy.

Keywords: retinoscopy; autorefraction; repeatability; validity; dioptric power.

Introduction

Static retinoscopy and autorefraction are two well-known objective methods of determining refractive error in patients.[1,2] Retinoscopy is best performed under scotopic conditions as this increases the contrast between the environment and the pupillary red reflex and allows for pupil dilation.[3] To obtain accurate results, the patient has to relax ocular accommodation; this can either be achieved by the use of fogging lenses, which are positive lenses used to control accommodation, or the use of cycloplegic drugs, which are used to temporarily paralyse accommodation.[4] The patient looks at a stationary distant target throughout the procedure and a 6/60 Snellen letter can be used as a target to get reliable results.[2,5]

Owing to the nature of the study group chosen for this research project, being adults with a relatively stable accommodative system, the use of fogging lenses was sufficient to relax accommodation and consequently there was less of a need for cycloplegic drugs. When comparing the two refractive methods of interest, this is helpful as clinically for adults these methods are usually used without cycloplegia.

There are numerous autorefractors available with a variety of designs and measurement principles. Different instruments can cause small clinically significant variations in the measurements, possibly because of the differences in measurement principles and design. However, the instruments have improved over time, and this has allowed for better accuracy and reliability of results.[6] Several studies have compared autorefraction to subjective refraction and/or retinoscopy, sometimes across different autorefractors.[7,8,9,10,11,12,13,14,15,16,17] However, subjective refraction remains the gold standard as it considers aspects such as patient comfort and communication, optical and/or neural factors and accuracy of the eventual prescription.[7,8] Studies have often compared the results produced by different autorefractors or investigated reliability of retinoscopy results,[7,8,9,10,11,12,13,14,15,16,17] but not many have compared the two against each other. To bridge the gap, this research project has focussed on inter-examiner retinoscopy, and additionally, these retinoscopy results will be compared to autorefractions for the same eyes. This will help us determine the accuracy of both autorefraction and retinoscopy.

The primary aim of this study was to evaluate inter-examiner repeatability during non-cycloplegic retinoscopy. The secondary aim was to assess its validity by comparing results for retinoscopy with non-cycloplegic autorefraction (table-mounted) as the criterion standard.

Research methods and design

Study design and setting

The study used a prospective observational and quantitative design and took place in a research and clinical department within a South African university.

Study population

Convenience, non-random sampling was used to obtain a sample of 68 adult participants: 35 men (51.5%) and 33 women (48.5%) that were predominantly of African descent (60.3%). The age range was from 18 years to 25 years with the mean age and standard deviation (s.d.) of 22.5 ± 0.71 years. The sample size was chosen conveniently based on time constraints and coronavirus disease 2019 (COVID-19) regulations that were put into play at the time of the study. The inclusion criteria were adults aged between 18 years and 25 years, with eyes with no pathologies and normal vision (i.e., visual acuity [VA] of 6/6 or better with or without refractive compensation). The exclusion criteria and factors affecting the results for this study were the presence of any systemic (i.e., uncontrolled diabetes or hypertension) or ocular diseases that affect the refractive error; conditions such as cataracts or corneal opacities that may impact refractometer readings, keratoconus that could result in scissor motion with retinoscopy, amblyopia or any strabismus conditions, a history of previous ocular surgery or where profound difficulties occurred to understand or comply with any of the objective refractive methods of this study. If patients were not aware of the excluded conditions, their measurements would have been excluded from the sample.

Methods

The baseline refractive status for the right eyes only of each participant was initially measured using an NIDEK AR-16 autorefractor by a student optometrist not performing retinoscopy. To ensure correct calibration, multiple measurements were performed on a –4 Dioptre (D) test eye prior to commencement of the study measurements. Thereafter, two senior student examiners with at least 3 years of experience performed three static retinoscopy measurements on the same adult participants under constant environmental conditions, and inter-examiner reliability of retinoscopy was analysed by comparing the average of the three results obtained by each examiner. Thus, retinoscopy was performed on the participants' right eyes by two senior student examiners (Examiner 1: TO, Examiner 2: SS), and retinoscopy reflexes were neutralised by using both spherical and cylindrical lenses in a phoropter. Room lighting was controlled by using two testing rooms with the same lighting set up, that is, with the same lighting controls and block out roller blinds. To maintain a working distance of 67 cm (from retinoscope to the phoropter), a 67 cm string was tied to the handle of the retinoscope. Refraction results were obtained from participants in the same order, that is, autorefraction followed by Examiner 1 and then Examiner 2, respectively. Examiners were masked to retinoscopy and autorefraction results. Therefore, in total, nine measurements of refractive state were taken per right eye of each participant, and subsequently the data set comprised one averaged autorefraction result and two averaged retinoscopy results, obtained independently from Examiner 1 and Examiner 2.

Data analysis

Once the data were obtained, measurements were analysed using mainly MATLAB and STATISTICA software programmes. Multivariate software (based on MATLAB) for analysis of dioptric power and refractive state was used. Once the sphere, cylinder and axis measurements of refractive state in clinical notation, namely F_s F_c A (or S C A) were determined, the refractive variables were transformed to dioptric power matrices ($\boldsymbol{F}$)[19,20,21,22,23,24,25,26,27,28,29,30] and power vectors ($\boldsymbol{f}$)[31] and their coefficients F_I, F_J and F_K. These three coefficients are the same as M, J_0 and J_{45} from Thibos et al.,[30] where M is the nearest equivalent sphere or spherical equivalent refraction (SER) power and J_0 and J_{45} are the powers of Jackson cross cylinders (JCC) with principal axes at 0 and 90° and at 45° and 135°, respectively[32] (Equation 1, Equation 2, Equation 3):

$$F_I = M = \text{(Spherical equivalent)} = \text{sphere} + \frac{1}{2}\text{ (cylinder)} \quad \text{[Eqn 1]}$$

$$F_J = J_0 = -\text{ (cylinder / 2)} \times \cos\text{ (2} \times \text{axis)} \quad \text{[Eqn 2]}$$

$$F_I = J_{45} = -\text{ (cylinder / 2)} \times \sin\text{ (2} \times \text{axis)} \quad \text{[Eqn 3]}$$

Bland-Altman plots and their mean differences, limits of agreement (LoA) and confidence intervals (CI) were also used to understand inter-examiner repeatability and validity. Wilcoxon matched pairs signed rank tests were used to determine statistically significant inter-examiner and validity differences. Pearson's correlations were used to investigate proportional bias, where $P < 0.05$ was considered statistically significant. Multivariate statistical analysis included stereo-pair scatter plots with 95% distribution ellipsoids and trajectories.

Ethical considerations

The study was approved by the University of Johannesburg Research Ethics Committee with reference no. REC01-184-2016 and the conduct of the study adhered to the tenets of the Declaration of Helsinki[18] and was approved by Higher Degrees and Research Ethics Committees of the University of Johannesburg. Participants gave informed consent to participate in the study before taking part. Participants and the public were not involved in the design, conduct, reporting or dissemination plans for the research. Consent forms and a questionnaire regarding general and ocular health were completed by each participant prior to testing and participants were informed that their participation was voluntary, thereby eliminating undue influence, and participation was conditional on that anonymity of participants be maintained. In addition, participants were informed that they could withdraw consent before submitting the data. However, withdrawal may not take place beyond that point as the data became anonymous.

Results

Univariate statistical analysis and descriptive reporting

Table 1 details the medians, inter-quartile ranges (IQRs) and ranges for the spherical, cylindrical and vector components as determined by Examiner 1 and Examiner 2 for inter-examiner repeatability, as well as the retinoscopy and autorefraction results for validity. The vector component M represents the (stigmatic) equivalent refractions (SER), and J_0 and J_{45} vector components represent the two anti-stigmatic or JCC powers, respectively.

TABLE 1: Medians, inter-quartile ranges and ranges for the spherical (S), cylindrical (C), spherical equivalent refraction (M) and J_0 and J_{45} vector components of refractive error for Examiner 1, Examiner 2 and autorefraction measurements.

Variables	Inter-examiner repeatability		Validity
	Examiner 1 measurements	Examiner 2 measurements	Autorefraction measurements
Median Sphere	-0.25	-0.50	-0.25
Interquartile range	2.25	2.25	2.00
Range	-7.30 to 1.25	-7.3 to 1.50	-7.00 to 1.00
Median Cylinder	-0.13	-0.25	-0.50
Interquartile range	0.63	0.75	0.50
Range	-2.50 to 0.00	-3.00 to 0.00	-2.80 to 0.00
Median M (SER)	-0.38	-0.50	-0.44
Interquartile range	2.63	2.31	2.38
Range	-8.10 to 1.25	-8.30 to 1.38	-7.90 to 0.88
Median J_0	0	0	0.11
Interquartile range	0.19	0.25	0.35
Range	-1.10 to 1.25	-1.60 to 2.00	-1.40 to 1.25
Median J_{45}	0	0	-0.03
Interquartile range	0	0	0.14
Range	-0.60 to 0.48	-0.50 to 0.63	-0.60 to 0.24

Note: Sample was 68 right eyes and units are dioptres throughout.
SER, (stigmatic) equivalent refractions.

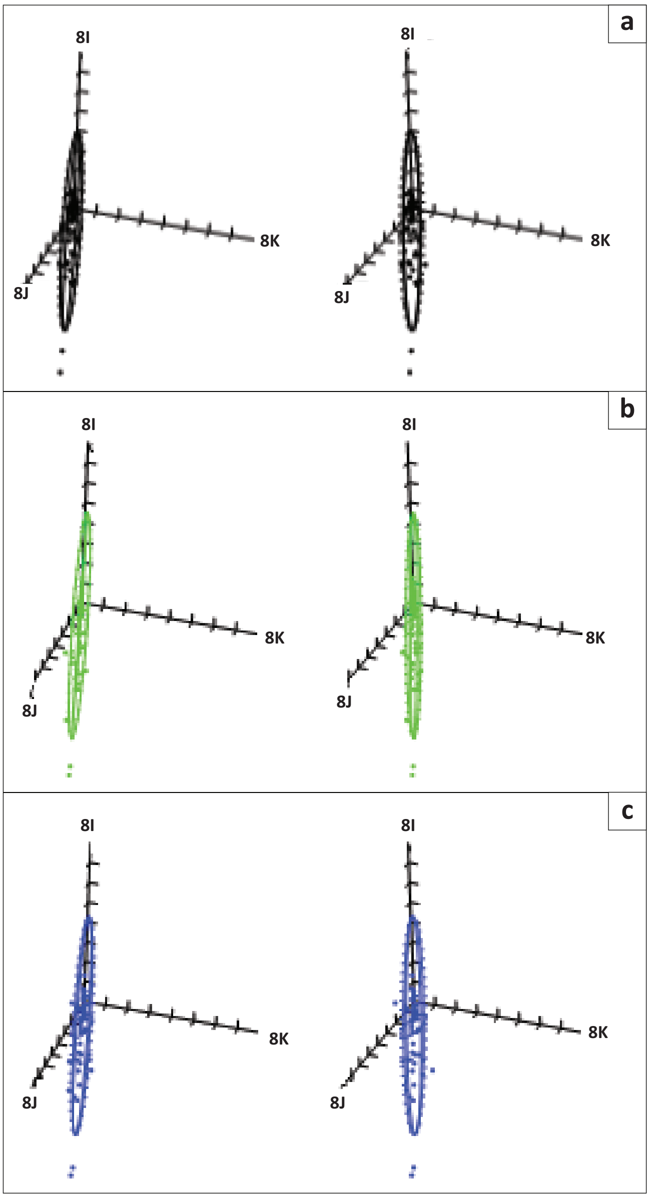
Refractive error analysis

Multivariate analysis

Stereo-pair scatter plots with 95% surfaces of constant probability density or distribution ellipsoids (Figure 1a, Figure 1b and Figure 1c) in symmetric dioptric power space (SDPS) for the refractive errors of the right eyes of 68 participants are indicated. Approximately 95% of sample measurements are expected to be found within the corresponding distribution ellipsoid. The centroid or centre of the ellipsoid indicates the estimated mean of the sample and the shape, orientation, maximum and minimum diameters, and the size and volume of the ellipsoid provide further information about sample variation and normality and possible outliers. The autorefractor measurements are illustrated with 68 black points, mostly within a black ellipsoid (Figure 1a), retinoscopy results by Examiner 1 are indicated with 68 green points and their ellipsoid (Figure 1b) and the 68 blue points and their ellipsoid represent retinoscopy results from Examiner 2 (Figure 1c). All ellipsoids have their longest axes falling roughly about the $F_1\mathbf{I}$ axis (=$M\mathbf{I}$ axis), thereby suggesting that variation in data is mainly spherical. The ellipsoids each have a centre or centroid representing the means of each of the three samples (in Figure 1; see Table 2). Descriptive statistics for these 95% distribution ellipsoids can be found in Table 2, and $S_{MM,}$ S_{J0J0} and S_{J45J45} represent the stigmatic and anti-stigmatic variances for M, J_0 and J_{45}, respectively. Variances are always positive and the larger the variance, the greater the variability of that coefficient of power for the sample concerned. The remaining entries in Table 2 are the covariances S_{J0M}, S_{J45M} and S_{J45J} that represent the linear relationships and covariation between variances for M and J_0, M and J_{45} and J_0 and J_{45}, respectively. Covariances can be negative or positive and the further away from zero, the greater the strength of the positive or negative linear relationship. If no linear relationships exist, then the covariances will all be zero (0 D^2). The square roots of the variances (S) are their corresponding standard deviations (s.d.), that is, $(\sqrt{S\ D^2} = \text{s.d.}\ \text{D})$.

In Table 2, the conventional or clinical means for autorefraction for Examiner 1 and Examiner 2 are essentially the same, suggesting that mean refractive error does not differ much from retinoscopy to autorefraction or across the two retinoscopy samples from Examiner 1 and Examiner 2. The variance row vectors in Table 2 display the stigmatic and anti-stigmatic variances for the given samples. All samples display mostly stigmatic or spherical variation as S_{MM} is larger in value than the anti-stigmatic variances of S_{J0J0} and S_{J45J45}. Covariances are composed of mixed positive and negative values (–0.21 to 0.05 D^2) but are close to zero; therefore, essentially there is little to no evidence for linear relationships between the variables (variances) concerned with S_{J0M} in all cases being possible exceptions but values are still not far from zero.

In the last column of Table 2, volumes for the 95% ellipsoids for the right eyes, Examiner 2 (blue ellipsoid) and autorefraction results (black ellipsoid) at 2.68 and 2.36 D^3, respectively, are greater than the volume for Examiner 1 (green ellipsoid; 1.77 D^3),



Note: The axis lengths are 8I D, and tick intervals of 1I, 1J and 1K D and the origin is at O D (or emmetropia). For each sample, approximately 95% of measurements are within the ellipsoid concerned with 5% of points being outside the confines of the ellipsoid. Readers should allow their eyes to diverge to an imaginary point behind the page when observing each of the stereo-pairs in the figure. This results in a third plot appearing in the middle between the two halves of each stereo-pair, and this central plot has a 3-dimensional appearance. Note possible outliers below the ellipsoids in (a), (b) and (c).

FIGURE 1: Stereo-pair scatter plots and 95% distribution ellipsoids for right eyes of 68 participants for (a) autorefraction measurements indicated by black points and a black ellipsoid, (b) Examiner 1 retinoscopy measurements and ellipsoid plotted in green and (c) the blue points and ellipsoid representing the Examiner 2 retinoscopy measurements.

suggesting greater spread of data and hence greater variation across participants (or at least for their data from Examiner 2 where ortho–anti-stigmatic variance with retinoscopy was larger suggesting that cylinder and axes were more variable with the results for retinoscopy from Examiner 2).

As observed in Figure 1, refractive errors in these 68 right eyes mostly ranged from hyperopia of about 3 D to myopia of about −5 D with cylinders with magnitudes < 2 D. There were two eyes that were more myopic than −5 D (see points and possible outliers below the ellipsoids in Figure 1).

Inter-examiner repeatability of retinoscopy

Descriptive results for the Bland-Altman plots, including means, mean differences, 95% LoA and 95% CI for inter-examiner repeatability, are detailed in Table 3 and Figure 2. In Figure 2, Bland-Altman plots[33,34,35,36,37,38] for the sample of 68 right eyes illustrate the agreement between Examiner 1 and Examiner 2 for their retinoscopy measurements, using the spherical (S or F_s), cylindrical (C or F_c), spherical equivalent ($M = F_I$), ortho–anti-stigmatic ($J_0 = F_J$) and oblique–anti-stigmatic ($J_0 = F_K$) coefficients of power, respectively. In the figures, the solid black horizontal line represents the mean difference ($\bar{X}_d$), and the 95% LoA are represented by the dashed upper and lower black lines that lie within their 95% CI represented by the shaded areas. If agreement for the two examiners was exact or perfect, mean differences $\bar{X}_d = 0$ D, standard deviation for the differences $s_d = 0$ D, standard error (SE) for $\bar{X}_d$ would be 0 D and the LoA range = 0 D. Also, all horizontal lines and points would be located on a single horizontal line with a *y*-coordinate of 0 D, and therefore all one would see would be a single horizontal line with 68 dots on it although some might overlap.

The means ($\bar{M}$) in Table 3 are the global averages for Examiner 1 and Examiner 2 measurements for the 68 right eyes of the participants. The mean power and its standard deviation (*s*) for the spherical equivalent coefficient (*M*) for the 68 right eyes are –1.12 ± 1.91 D; therefore, about 68% of measurements ($\bar{M} \pm 1\, s$) had spherical equivalent powers of between –3.03 D and 0.79 D.

Mean differences ($\bar{X}_d$) were less than one clinical step (0.25 D) for all refractive error variables (ranging from –0.11 D to 0.08 D), indicating good repeatability and agreement for Examiner 1 and Examiner 2 measurements.

The 95% LoA for the ortho–anti-stigmatic (J_0) and oblique–anti-stigmatic (J_{45}) coefficients span narrower intervals (J_0: $LoA_R = 1.26$ D, *J*45: $LoA_R = 0.66$ D) than that for the other variables, that is, spherical (*S*: $LoA_R = 1.44$ D), cylindrical (C: $LoA_R = 1.64$ D) and spherical equivalent (*M*: $LoA_R = 2.31$ D), suggesting that inter-examiner JCC powers were more similar across the two examiners, and all SE and CI associated with the $\bar{X}_d$ and LoA were small (≤ 0.12 D).

Concerning the intraclass correlation coefficients (*ICC*) in Table 3, most values are greater than 0.5 and close to 1, indicating high reliability between values from the samples. However, oblique–anti-stigmatic coefficients (J_{45}) can be seen as having poorer reliability between *test* and *retest* measurements ($ICC < 0.5$).

In Table 3, non-parametric Wilcoxon matched pairs tests applied to the refractive error variables for retinoscopy to compare matched or related measurements (that is, for the same participants) for the Examiner 1 and Examiner 2 indicated that no statistically significant differences were found for the spherical (*S*) and JCC (J_0 and J_{45}) components. There were significant differences for *M* across the two examiners.

TABLE 2: Statistical variables for the right eyes of 68 participants for autorefraction, Examiner 1 and Examiner 2 retinoscopy measurements, including clinical means, vector notation means, vector notation variances and covariances and volumes of 95% distribution ellipsoids (N = 68).

Variables	Clinical means†	Means‡			Variances			Covariances			Volumes¶
		M	J_0	J_{45}	S_{MM}	S_{J0J0}	S_{J45J45}§	S_{J0M}	S_{J45M}	S_{J45J0}§	
Autorefraction	-0.98 – 0.24 × 169	-1.094	0.110	0.044	3.118	0.142	0.020	-0.139	0.029	0.005	2.361
Examiner 1	-1.00 – 0.19 × 175	-1.099	0.096	0.015	3.817	0.097	0.018	-0.213	0.047	0.013	1.766
Examiner 2	-0.97 – 0.34 × 1	-1.145	1.172	0.006	3.682	0.186	0.017	-0.169	0.015	0.005	2.677

Note: The variances of M, J_0 and J_{45} are represented by S_{MM}, S_{J0J0} and S_{J45J45} respectively; S_{MM} is the spherical equivalent variance, while S_{J0J0} and S_{J45J45} are the Jackson Cross cylinder variances. S_{J0M}, S_{J45M} and S_{J45J0} are covariances (see Figure 1).

†, Units for clinical means are in dioptres and degrees (D, D, °); ‡, Units for vector (f) notation means are in dioptres (D); §, Units for vector notation variances and covariances are in squared dioptres (D^2); ¶, Units for volumes of 95% distribution ellipsoids are in cubic dioptres (D^3).

TABLE 3: Descriptive statistics for the Bland-Altman plots in Figure 2 for the spherical (S), cylindrical (C), stigmatic or spherical equivalents (M) and anti-stigmatic or JCC (J_0 and J_{45}) components for inter-examiner repeatability for retinoscopy (N = 68 right eyes).

Variables	Inter-examiner repeatability for retinoscopy Examiner 1 vs Examiner 2				
	Spheres S	Cylinders C	Spherical equivalent coefficients $M = F_I$	Ortho-anti-stigmatic coefficients $J_0 = F_J$	Oblique-anti-stigmatic coefficients $J_{45} = F_K$
$\bar{M}$ (s.d. of means)	-0.92 (1.72)	-0.44 (0.59)	-1.12 (1.91)	0.13 (0.34)	-0.01 (0.10)
$\bar{X}_d$ (s.d. of difference)	-0.04 (0.36)	-0.11 (0.42)	-0.05 (0.58)	0.08 (0.32)	0.02 (0.17)
SE for $\bar{X}_d$	0.04	0.05	0.07	0.04	0.02
LLoA; ULoA	-0.77; 0.67	-0.94; 0.70	-1.21; 1.10	-0.56; 0.70	-0.31; 0.35
LoA_R range	1.44	1.64	2.31	1.26	0.66
SE for LoA	0.08	0.09	0.12	0.07	0.03
(LCI; UCI) for $\bar{X}_d$	-0.4; 0.32	-0.53; 0.3	-0.63; 0.54	-0.24; 0.39	-0.14; 0.19
CI range for $\bar{X}_d$	0.72	0.83	1.17	0.63	0.33
ICC	0.98	0.77	0.95	0.63	0.20
Wilcoxon matched pairs tests					
z	1.72	2.02	2.56	1.90	0.87
p	0.08	0.04	0.01	0.06	0.38
Statistically significant difference?	No	No	Yes	No	No

Note: Units are dioptres (D) except where not applicable as in the last two rows. A Bonferroni correction (P = 0.05/5 = 0.01) for the five tests or comparisons was applied to the level of significance and only measurements for M were significantly different across examiners although clinically the mean difference ($\bar{X}_d$ = −0.05 D) and standard deviation (s.d.) for the differences (s.d. = 0.58 D) were not far from zero.

LLoA, Lower Limits of Agreement; ULoA, Upper Limits of Agreement; LCI, Lower Confidence Interval; UCI, Upper Confidence Interval; CI, confidence interval; SE, standard error; ICC, intraclass correlation coefficients, M, means; X, mean differences.

The Bland-Altman plots in Figure 2 also include Pearson's correlation coefficients (and corresponding P-values) for the specific means and differences concerned. If the means and differences are not correlated, then r would be close to zero. If $P < 0.05$, then the correlation is significant at a 95% level of confidence. Most components were non-significant. Outliers can be important for the interpretation of these plots and P-values as in part d). If you were to remove the outlier (top in d), the plot, and maybe the P-value, would change and the P-value might be non-significant. Part d) was the only one where P was significant and it is probably misleading because of the single outlier.

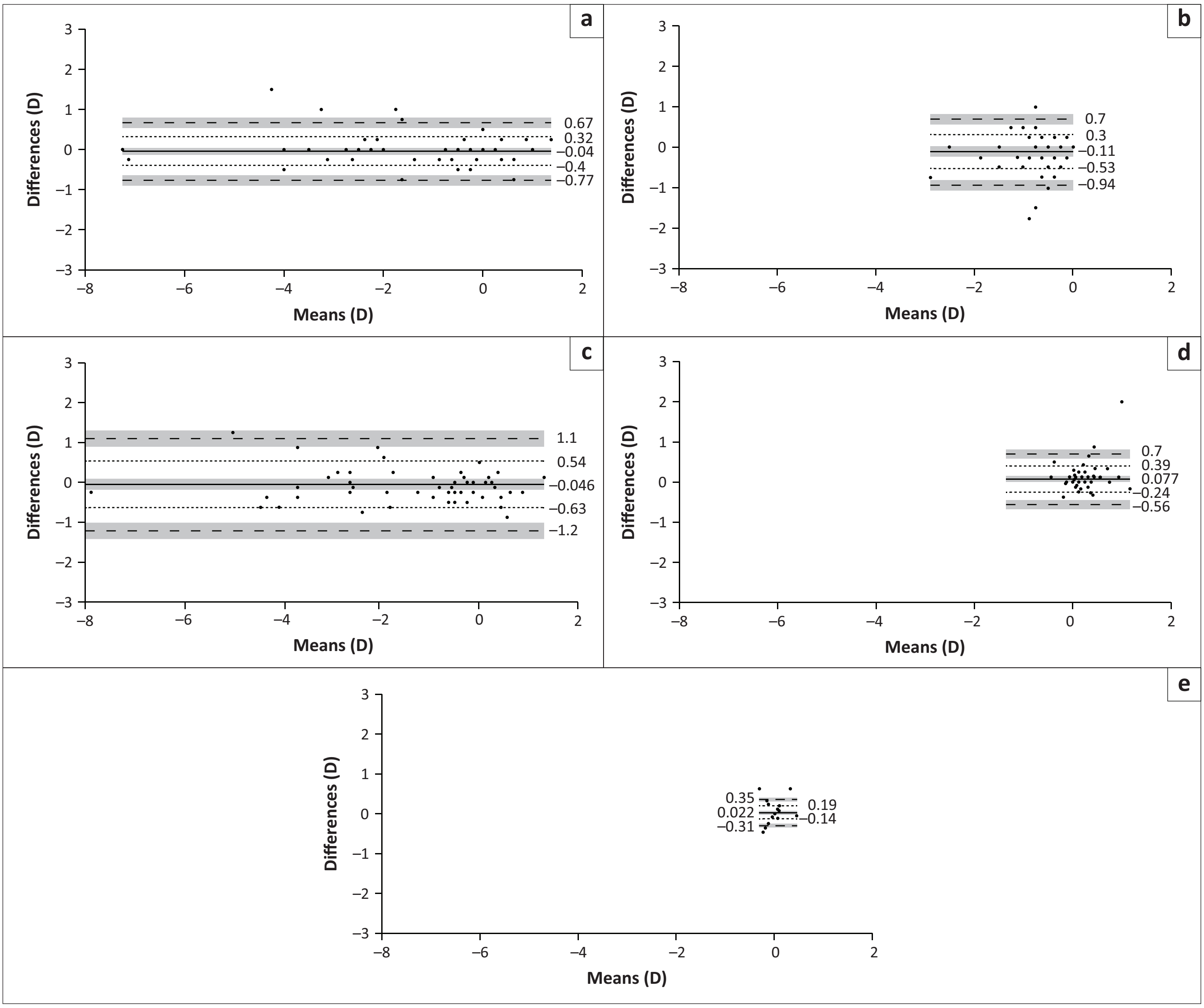
Validity of retinoscopy to autorefraction

The Bland-Altman plots in Figure 3 and Figure 4 have been generated to graphically illustrate the agreement between the autorefraction measurements with that for retinoscopy from both Examiner 1 and Examiner 2 for the right eyes of 68 participants. Table 4 contains the descriptive statistics for the data concerned. Mean differences ($\bar{X}_d$) were again generally found to be less than or equal to one clinical step (0.25 D) for all refractive error variables (ranging from –0.13 D to 0.25 D for Examiner 1 and –0.17 D to 0.13 D), indicating good repeatability and agreement for Examiner 1 and Examiner 2 measurements of retinoscopy against autorefraction.

In Figure 3 and Table 4, it can be seen that the 95% LoA for Examiner 1 against autorefraction span narrower intervals for all refractive error variables (C: LoA_R = 1.66 D, M: LoA_R = 2.27 D, J_0: LoA_R = 0.97 D, J_{45}: LoA_R = 0.57 D) with the exception of the spherical component that was larger (S: LoA_R = 2.16 D), when compared with the LoA ranges found for Examiner 2 against autorefraction in Figure 4 (S: LoA_R = 1.94 D, C: LoA_R = 1.83 D, M: LoA_R = 2.65 D, J_0: LoA_R = 1.49 D, J_{45}: LoA_R = 0.72 D). This suggests that agreement between the two methods was better for Examiner 1 rather than Examiner 2. However, SE associated with the $\bar{X}_d$ and the LoAs is small (≤ 0.14 D) for both examiners against autorefraction.

Concerning the ICC in Table 4, most values are greater than 0.5 and close to 1, indicating high reliability between values from the samples. However, oblique–anti-stigmatic coefficients (J_{45}) can be seen as having poorer reliability between *test* and *retest* measurements (ICC < 0.5).

In Table 4, Wilcoxon matched pairs tests to compare retinoscopy and autorefraction measurements for Examiner 1 indicated that a statistically significant difference was found for only the cylindrical component (C) (z = 4.26; P = 0.00). However, for Examiner 2, statistically significant differences were found for the spherical (S) (z = 2.67; P = 0.01) and J_{45} (z = 2.59; P = 0.01) components. Therefore, retinoscopy measurements made by Examiner 1 are considered as being more valid against the corresponding autorefraction results for the participants concerned.



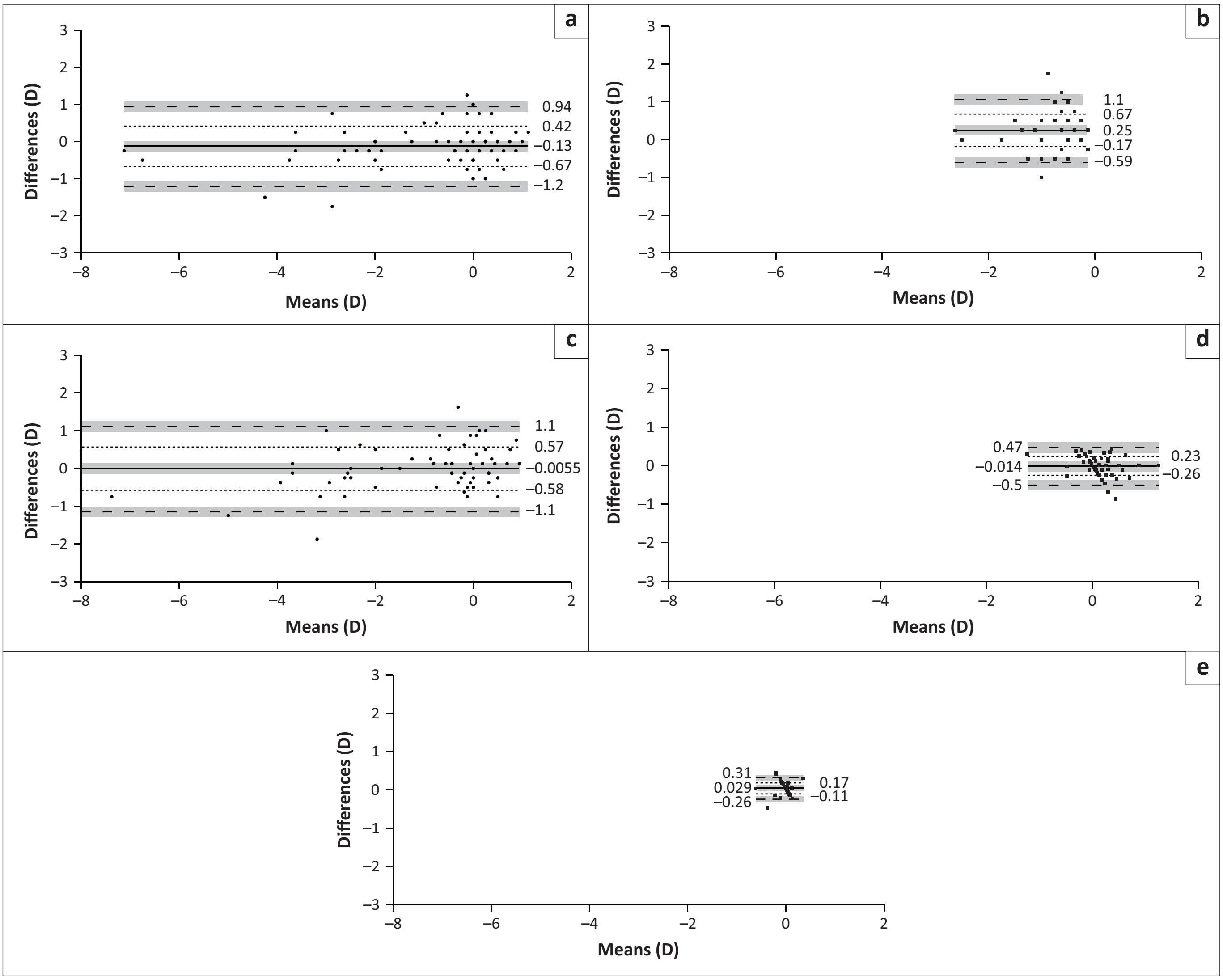
Note: Results for participants are indicated with black dots. Each plot has a title that refers to the coefficient concerned, that is, sphere (*S*) in part a, cylinder (*C*) in part b, spherical equivalent (*M*) in part c, and anti-stigmatic or Jackson Cross cylindrical components J_0 and J_{45} in parts d and e, respectively. In each part, the solid black horizontal line indicates the mean difference ($\bar{X}_d$) while the upper and lower limits of agreement (LoA) are represented by the dashed black lines that each lie within their own 95% exact confidence intervals (*CI*) (Harris 2001) as represented by the grey shaded regions. Two black dotted lines represent the $\bar{X}_d$ ± 1 s.d. Differences were calculated by subtracting the corresponding Examiner 2 from Examiner 1 measurements for the right eyes of the 68 participants. The Bland-Altman plots also include Pearson's correlation coefficients (and corresponding *P*-values) for the specific means and differences concerned. If the means and differences are not correlated, then r would be close to zero. If $P < 0.05$, then the correlation is significant at a 95% level of confidence. Outliers can be important for interpretation of these plots and *P*-values as in part d) for C. Scales in all parts (a to e) are identical for ease of comparison

FIGURE 2: Bland-Altman plots of means *versus* differences of Examiner 1 and Examiner 2 retinoscopy measurements for right eyes of 68 participants, aged 18–25 years for (a) Spherical component (r = –0.22, P = 0.076); (b) Cylindrical component (r = 0.21, P = 0.085); (c) Spherical equivalent component (M) (r = –0.061, P = 0.62); (d) Cylindrical component (J0) (r = 0.41, P = 0.00052) and (e) Cylindrical component (J45) (r = –0.36, P = 0.77).

Discussion

Results for retinoscopy for both examiners as well as autorefraction measurements were displayed graphically by means of stereo-pair scatter plots with 95% distribution ellipsoids. Additionally, Bland-Altman plots to establish inter-examiner repeatability for retinoscopy and validity of retinoscopy to autorefraction were applied. Stereo-pair scatter plots indicated similarities between examiners for retinoscopy.

Table 2 also confirmed that clinical means for autorefraction and retinoscopy were essentially the same, and similarly, variances and covariances were similar across samples. This was true despite the lack of cycloplegia, relative inexperience of the student examiners and limited number of eyes (68) involved. The Bland-Altman analysis also largely supported these findings with small mean differences (≈ 0 D) and ICC between 0.1 and 0.95; although there were a limited number of possible outliers, removal of which would likely further strengthen the argument and agreement between examiners, methods and samples. For example, in Figure 2d, if you were to remove the outlier (top in d), the plot, and maybe the *P*-value, would change and the *P*-value might be non-significant. Part d) was the only one where *P* was significant and it is probably misleading because of the single outlier. The influence of outliers has been expanded upon in,[35] in which the identification and removal of certain outliers were performed, and issues such as normality, variances, covariances, surfaces of constant probability density and tests for equality were re-visited with the modified data to



Note: (Each eye is indicated with a black dot.) Parts (a) and (b) are the Bland-Altman plots for the spherical (*S*) and cylindrical (*C*) components, while parts (c), (d) and (e) are the spherical equivalents (*M*) and the ortho–anti-stigmatic (J_0) coefficients and the oblique–anti-stigmatic (J_{45}) coefficients of power, respectively, for the right eyes.

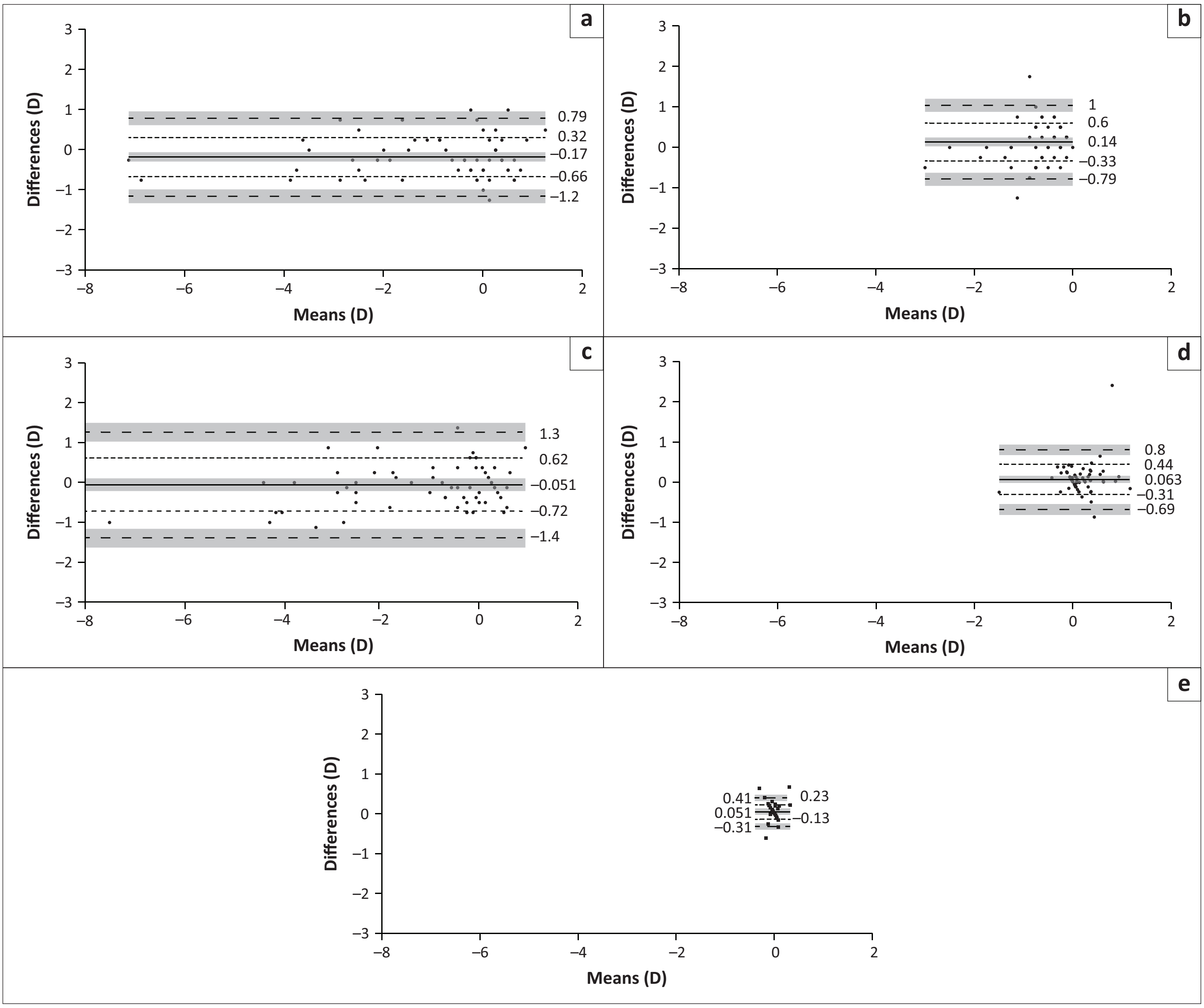
FIGURE 3: Bland-Altman plots of means versus differences for Examiner 1 retinoscopy measurements and autorefraction for 68 right eyes for (a) Spherical component (r = 0.21, P = 0.08); (b) Cylindrical component (r = 0.11, P = 0.35); (c) Spherical equivalent component (M) (r = 0.33, P = 0.0056); (d) Cylindrical component (J0) (r = –0.28, P = 0.021) and (e) Cylindrical component (J45) (r = –0.078, P = 0.053).

demonstrate their influences on some samples or distributions of data. The removal of the identified outliers in the samples, which had larger magnitudes of cylinder, resulted in changes (a decrease) in the variances of certain components of dioptric power for the samples concerned, which in turn improved the normality of the components of power. Therefore, removing these outliers can have important implications relating to analysis and application of data.

However, LoA ranged from only 0.57 D to 2.65 D with mostly larger LoA_R for the spherical (*S*) and spherical equivalent (*M*) coefficients of power. The use of cycloplegia and examiners with greater clinical experience with retinoscopy would have likely reduced these larger ranges. Despite these issues, only 3 of the 15 Wilcoxon tests suggested significant differences in samples at an adjusted *P*-value of < 0.01. (If the unadjusted $P < 0.05$ is used instead, then this changes to six of 15 tests or 40% of comparisons.) Removal of a few potential outliers might reduce these percentages.

In the Bland-Altman plots, mean differences ($\bar{X}_d$) were less than or equal to one clinical step (0.25 D) for all refractive error variables, indicating repeatability and agreement for Examiner 1 and Examiner 2 measurements for retinoscopy, as well as for both examiner's measurements of retinoscopy against autorefraction in the validity section. There were no statistically significant differences between the two examiners for the spherical (*S*) component and JCC vector components (J_0 and J_{45}). These findings are comparable with results from McCullough et al.[39] for intra- and inter-examiner repeatability of cycloplegic retinoscopy among young children.

The ranges for 95% limits of agreement for both inter-examiner repeatability of retinoscopy and validity of retinoscopy against autorefraction indicate differences between examiners and refractive methods of > 1 D for most but not all refractive error coefficients (see Table 3 and Table 4). Some of the contributing factors are already described earlier, but these findings are nonetheless



Note: Parts (a) to (e) are the same as for Figure 3.

FIGURE 4: Bland-Altman plots of means versus differences for Examiner 2 retinoscopy measurements and autorefraction for 68 right eyes indicated using black dots for (a) Spherical component (r = 0.075, P = 0.54); (b) Cylindrical component (r = 0.3, P = 0.014); (c) Spherical equivalent component (M) (r = 0.23, P = 0.057); (d) Cylindrical component (J0) (r = –0.17, P = 0.017) and (e) Cylindrical component (J45) (r = –0.1, P = 0.4).

comparable with results from McCullough et al.[39], Zadnik et al.[40] and Walline et al.[41]

Using the unadjusted $P < 0.05$, statistically significant differences were found for the cylindrical component (C) between the two examiners (for retinoscopy), as well as between autorefraction and retinoscopy measurements for each examiner. One reason for this difference could be owing to the sensitivity of the determination of principal meridians during retinoscopy and given the level of experience of the two examiners. A study by Paysse et al.[36,] revealed that off-axis retinoscopy produces significant alterations to the results. Their study involved eight volunteers and an examiner performed cycloplegic retinoscopy on them. An analysis of their results revealed that for each degree off-axis, cylindrical power increased by ≈3%. The method used to determine whether the axis is correct is by checking for a thinner and brighter reflex. If the examiner observes a wide, dim and distorted reflex, this means that they are off-axis.

In this study, autorefraction and retinoscopy for both examiners were found to be clinically similar, agreeing with previously published studies such as Mukash et al.[16] and Hasrod.[35] However other studies such as Jorge et al.[42] and Rotsos et al.[43] that have compared retinoscopy and autorefraction found disagreement. Such disagreement stems from the fact that different autorefractor models are available and the performance of these models needs to be compared with each other as well as with other refractive methods such as retinoscopy or subjective refraction. Some studies, however, showed agreement between retinoscopy and autorefraction also compared both methods to subjective refractions to show whether there were correlations and/or agreement between methods.[7,8,9,10,11,12,13,14,15,16,17]

A study to determine whether autorefraction or retinoscopy is the better starting point for subjective refraction was performed by Jorge et al.[42] They concluded

TABLE 4: Descriptive statistics for the Bland-Altman plots in Figure 3 and Figure 4 for the spherical (S), cylindrical (C), stigmatic or spherical equivalents (M) and anti-stigmatic or JCC (J_0 and J_{45}) components for validity of retinoscopy measurements from Examiner 1 and Examiner 2 against autorefraction (N = 68 right eyes).

Validity	Spheres S	Cylinders C	Spherical equivalent coefficients M	Ortho-anti-stigmatic coefficients J_0	Oblique-anti-stigmatic coefficients J_{45}
Autorefraction VS Examiner 1					
$\bar{M}$ (s.d. of means)	-0.84 (1.69)	-0.51 (0.52)	-1.10 (1.84)	0.10 (0.32)	-0.03 (0.12)
$\bar{X}_d$ (s.d. of differences)	-0.13 (0.54)	0.25 (0.42)	-0.01 (0.57)	-0.01 (0.24)	0.23 (0.14)
SE for $\bar{X}_d$	0.07	0.05	0.07	0.03	0.12
LLoA; ULoA	-1.22; 0.94	-0.59; 1.07	-1.15; 1.12	-0.50; 0.47	-0.26; 0.31
LoA range	2.16	1.66	2.27	0.97	0.57
SE for LoA	0.11	0.09	0.12	0.05	0.03
(LCI; UCI) for $\bar{X}_d$	-0.67; 0.42	-0.17; 0.67	-0.58; 0.57	-0.26; 0.23	-0.11; 0.17
CI range for $\bar{X}_d$	1.09	0.84	1.15	0.49	0.28
ICC	0.95	0.64	0.95	0.75	0.45
Wilcoxon matched pairs tests					
z	1.88	4.26	0.24	0.08	1.90
p	0.06	0.00	0.81	0.94	0.06
Statistically significant difference?	No	Yes	No	No	No
Autorefraction VS Examiner 2					
$\bar{M}$ (s)	-0.86 (1.66)	-0.57 (0.56)	-1.12 (1.81)	0.14 (0.36)	-0.02 (0.10)
$\bar{X}_d$ (s_d)	-0.17 (0.49)	0.13 (0.46)	-0.05 (0.67)	0.06 (0.37)	0.05 (0.18)
SE for $\bar{X}_d$	0.06	0.06	0.08	0.05	0.22
LLoA; ULoA	-1.15; 0.79	-0.79; 1.04	-1.39; 1.26	-0.69; 0.80	-0.31; 0.41
LoA range	1.94	1.83	2.65	1.49	0.72
SE for LoA	0.10	0.10	0.14	0.08	0.04
(LCI; UCI) for $\bar{X}_d$	-0.66; 0.32	-0.33; 0.6	-0.72; 0.62	-0.31; 0.44	-0.13; 0.23
CI range for $\bar{X}_d$	0.98	0.93	1.34	0.75	0.36
ICC	0.95	0.69	0.93	0.56	0.10
Wilcoxon matched pairs tests					
z	2.67	2.21	1.50	1.30	2.59
p	0.01	0.03	0.13	0.19	0.01
Statistically significant difference?	Yes	No	No	No	Yes

Note: A Bonferroni correction (P = 0.05/5 = 0.01) for the five tests or comparisons was applied to the level of significance.

LLoA, Lower Limits of Agreement; ULoA, Upper Limits of Agreement; LCI, Lower Confidence Interval; UCI, Upper Confidence Interval; CI, confidence interval; SE, standard error; ICC, intraclass correlation coefficients, M, means; X, mean differences.

that autorefraction and retinoscopy showed similar agreement and thus either could be used as a starting point for a subjective refraction. The current study broadly supports these results, showing that generally retinoscopy or autorefraction are both reliable as a starting point for a subjective refraction.[21]

Another study in Indonesia by Hardiyanti et al.[44] also examined the correlation between autorefractometry and retinoscopy with subjective refraction. They concluded that retinoscopy is superior to autorefractometry only because the retinoscopy showed a slightly stronger correlation to a subjective refraction than the autorefractometry. Although the current study did not compare results to a subjective refraction, there was a strong correlation between autorefraction and retinoscopy results.

Aboumourad and Anderson[45] in Houston, United States (US), also compared retinoscopy and autorefraction results for the measure of a patient's accommodative amplitude with 95% agreement between the techniques. Their research shows that results from retinoscopy and autorefraction used near to measure the accommodative amplitude of a patient do not greatly differ from one another. Because both the two techniques produced accommodative amplitude results that were less than 2 D, each technique is a suitable way to measure the accommodative amplitude. Therefore, whether these refractive methods are used for distance refractive state (as for the current study herein) or near for objective measurement of accommodative amplitudes, the methods (that is, retinoscopy and autorefraction) have good agreement and moderate to strong inter-correlation. Although correlations have not been discussed in much detail in the current article, they were determined and were mostly suggestive of moderate to strong positive correlations.

A study by Carkeet et al.[38] reviews the use of Bland-Altman plots in Optometry and Vision Science and explains that limits of agreement may be unreliable at times, because of factors such as outliers, small samples or relationships between variables such as means and differences. Overall, Carkeet et al.[38] reviewed 50 articles with Bland-Altman plots and sample sizes ranging from 3 to 2702, and they concluded that the use of CI for LoA is being used more often in eyecare fields such as Optometry, but there remains deviation from a universal way of analysing results. Therefore, research using Bland-Altman plots should ideally also use other means for analysing results, and some examples such as Figure 1 and Table 1 are included in this article and its analysis to show that refractive methods such as retinoscopy are comparable across examiners as well as to autorefraction.

Strengths and limitations of the study

The results of this study were assessed using mainly multivariate statistical methods for dioptric power and refractive behaviour, and this is one of few studies where such methods were applied to retinoscopy to assess inter-examiner repeatability. Possible limitations here are that the sample (n = 68 participants) was relatively small and selected via non-random convenience sampling rather than via a randomised selection, and thus results are not necessarily representative of the diversity present in the general population. During retinoscopy, although factors such as room lighting and working distance were controlled as best as possible, the working distance of each examiner may have unintentionally differed. Morton and Barrett's (1886)[46] Ocular accommodation was still active as cycloplegic drops were not administered, and the use of cycloplegic drops would restrict the effects of ocular accommodation and the influences of inaccuracies and possible outliers.[35] Further studies with larger sample sizes would be advantageous, and subjective refraction could be included for additional value. Repeated examinations on the same participants at another time of day, week or month would allow for comparisons of short- and long-term reproducibility.

Conclusion

Through careful analysis of the results obtained, it can be concluded that although statistically speaking there was slight variation between the measurement means made by the examiners (and against autorefraction), clinically, inter-examiner retinoscopy is comparable and reliable as results between the two examiners only differed by approximately 0.25 D. Given that the student examiners here are relatively new to retinoscopy, it can be concluded that retinoscopy done by a proficient examiner can be used as a reliable starting point. Retinoscopy and autorefraction are important techniques used to objectively determine a patient's prescription. Even though autorefractors have improved in terms of reliability and technology over the years, the autorefractor result should not replace a subjective refraction. Thus, by performing retinoscopy, examiners will obtain a reliable and accurate objective measurement of a patient's refractive error provided that the examiners are proficient in this procedure.

Acknowledgements

The author would like to extend their thanks to Professor Alan Rubin for discussions and reviewing the manuscript and to the student researchers and participants for their cooperation and involvement.

Competing interests

The author declares that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Author's contributions

N.H. is the sole author of this research article.

Funding information

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Data availability

The data that support the findings of this study are available from the corresponding author, N.H., upon reasonable request.

Disclaimer

The views and opinions expressed in this article are those of the author and are the product of professional research. The article does not necessarily reflect the official policy or position of any affiliated institution, funder, agency or that of the publisher. The author is responsible for this article's results, findings and content.

References

1. Cordero I. Understanding and looking after a retinoscope and trial lens set. Community Eye Health. 2017;30(98):40–41.
2. Chowdhury PH, Shah BH. All about static retinoscopy. Ophthalmol Res. 2018;9(1):1–3. https://doi.org/10.9734/OR/2018/40809
3. Elliott DB. Clinical procedures in primary eye care E-Book. Philadelphia: Elsevier Health Sciences; 2020.
4. Ranganathan KS. Fogging retinoscopy-a novel method to perform refraction under normal conditions. J Evid Based Med Healthc. 2019;6(13):1048–1051. https://doi.org/10.18410/jebmh/2019/218
5. Bhalla S, Mohan S. The lost art of dynamic retinoscopy. Delhi J Ophthalmol. 2015;25(2):141–143. https://doi.org/10.7869/djo.96
6. Domínguez-Vicent A, Al-Soboh L, Brautaset R, Venkataraman A. Effect of instrument design and technique on the precision and accuracy of objective refraction measurement. J Clin Med. 2020;9(10):3061. https://doi.org/10.3390/jcm9103061
7. Kumar R, Moe C, Kumar D, et al. Accuracy of autorefraction in an adult Indian population. PLoS One. 2021;16(5):e0251583. https://doi.org/10.1371/journal.pone.0251583
8. Paudel N, Adhikari S, Thakur A, Shrestha B, Loughman J. Clinical accuracy of the Nidek ARK-1 autorefractor. Optom Vis Sci. 2019;96(6):407–413. https://doi.org/10.1097/OPX.0000000000001386
9. Paysse EA, Jackson DW, Wilhelmus KR, Hussein MA, Rosby G, Coats DK. Effect of off-axis retinoscopy on objective refractive measurement. In Transactions 28th European Strabismological Association Meeting 2020 Aug 26. CRC Press; p. 79-81.
10. Menolotto M, Livingstone I, Giardini M. An imaging-based autorefractor – Strathprints [homepage on the Internet]. 2021 [cited 2021 Sep 03]. Available from: https://strathprints.strath.ac.uk/76281/
11. Bhat S, Kour V, Mushtaq T. Comparison of findings of autorefraction and retinoscopy with subjective acceptance between rural and urban school going children in Northern India. J Med Sci Clin Res. 2021;9(1):250–254. https://doi.org/10.18535/jmscr/v9i1.46
12. Wosik J, Patrzykont M, Pniewski J. Comparison of refractive error measurements by three different models of autorefractors and subjective refraction in young adults. J Opt Soc Am A Opt Image Sci Vis. 2019;36(4):B1–B6. https://doi.org/10.1364/JOSAA.36.0000B1
13. Vasudevan B, Ciuffreda KJ, Meehan K, Grk D, Cox M. Comparison of objective refraction in darkness to cycloplegic refraction: A pilot study. Clin Exp Optom. 2016;99(2):168–172. https://doi.org/10.1111/cxo.12367
14. Goss DA, Grosvenor T. Reliability of refraction – A literature review. J Am Optom Assoc. 1996;67(10):619–630.
15. Yuo YC, Wang JH, Chiu CJ. Comparison of open-field autorefraction, closed-field autorefraction, and retinoscopy for refractive measurements of children and adolescents in Taiwan. J Formo Med Assoc. 2020;119(8):1251–1258. https://doi.org/10.1016/j.jfma.2020.04.009
16. Mukash SN, Kayembe DL, Mwanza JC. Agreement between retinoscopy, autorefractometry and subjective refraction for determining refractive errors in Congolese children. Clin Optom. 2021;13:129. https://doi.org/10.2147/OPTO.S303286

17. Guha S, Shah S, Shah K, Hurakadli P, Majee D, Gandhi S. A comparison of cycloplegic autorefraction and retinoscopy in Indian children. Clin Exp Optom. 2017;100(1):73–78. https://doi.org/10.1111/cxo.12375

18. World Medical Association. Declaration of Helsinki: Ethical principles for medical research involving human subjects. J Am Med Assoc. 2013;310:2191–2194. https://doi.org/10.1001/jama.2013.281053

19. Harris WF. Algebra of sphero-cylinders and refractive errors, and their means, variance, and standard deviation. Am J Optom Physiol Opt. 1988;65:794–802. https://doi.org/10.1097/00006324-198810000-00003

20. Harris WF. Squaring the sphero-cylinder, the equivalent of squaring the refractive power matrix. Ophthalmic Physiol Opt. 1988;8(4):458–459. https://doi.org/10.1111/j.1475-1313.1988.tb01185.x

21. Harris WF. The matrix representation of dioptric power. Part 3: The average of refractive error. S Afr Optom. 1989;48:81–88.

22. Harris W. The mean and variance of samples of dioptric powers: the basic calculations. Clin Exp Optom. 1990;73(3):89–92. https://doi.org/10.1111/j.1444-0938.1990.tb03110.x

23. Harris WF. Elements of the dioptric power matrix and the concept of torsional power: A reinterpretation. Optom Vis Sci. 1990;67(1):36–7. https://doi.org/10.1097/00006324-199001000-00008

24. Harris WF. Comparison of dioptric power. Ophthalmic Physiol Opt. 1990;10(2):200–202. https://doi.org/10.1111/j.1475-1313.1990.tb00976.x

25. Harris WF. Statistical inference on mean dioptric power: Hypothesis testing and confidence regions. Ophthalmic Physiol Opt. 1990;10(4):363–372. https://doi.org/10.1111/j.1475-1313.1990.tb00883.x

26. Harris WF. Mean of a sample of equivalent dioptric powers. Optom Vis Sci. 1990;67(5):359–360. https://doi.org/10.1097/00006324-199005000-00010

27. Harris WF, Direct HWF. Direct, vec and other squares, and sample variance-covarianceof dioptric power. Ophthalmic Physiol Opt. 1990;10(1):72–80. https://doi.org/10.1016/0275-5408(90)90134-K

28. Harris WF. Representation of dioptric power in Euclidean 3-space. Ophthalmic Physiol Opt. 1991;11(1):130–6. https://doi.org/10.1111/j.1475-1313.1991.tb00212.x

29. Harris WF. Clinical measurement, artifact, and data analysis in dioptric power space. Optom Vis Sci. 2001;78(11):839–845. https://doi.org/10.1097/00006324-200111000-00014

30. Thibos LN, Wheeler W, Horner D. Power vectors: An application of Fourier analysis to the description and statistical analysis of refractive error. Optom Vis Sci. 1997;74(6):367–375. https://doi.org/10.1097/00006324-199706000-00019

31. Harris WF. Testing hypotheses on dioptric power. Optom Vis Sci. 1992;69(11):835–845. https://doi.org/10.1097/00006324-199211000-00002

32. Rubin A, Evans T, Hasrod N. Dioptric power and refractive behaviour: A review of methods and applications. BMJ Open Ophthalmol. 2022;7(1):e000929. https://doi.org/10.1136/bmjophth-2021-000929

33. Hasrod N, Rubin A. Comparison of the near eye tool for refractive assessment (NETRA) on non-cycloplegic subjective refraction. BMJ Open Ophthalmol. 2022;7(1):e000851. https://doi.org/10.1136/bmjophth-2021-000851

34. Hasrod N, Rubin A. Multivariate analysis of repeatability for the Near Eye Tool for Refractive Assessment (NETRA). BMJ Open Ophthalmol. 2023;8(1):e001458. https://doi.org/10.1136/bmjophth-2023-001458

35. Hasrod N. Inter- and intra-individual reliability of objective and subjective methods for determination of refractive state of the human eye [DPhil Thesis]. Johannesburg: Department of Optometry, Faculty of Health Sciences, University of Johannesburg; 2020.

36. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;1:307–310. https://doi.org/10.1016/S0140-6736(86)90837-8

37. Carkeet A. Exact parametric confidence intervals for Bland-Altman limits of agreement. Optom Vis Sci. 2015;92(3):e71–e80. https://doi.org/10.1097/OPX.0000000000000513

38. Carkeet A. A review of the use of confidence intervals for Bland-Altman limits of agreement in optometry and vision science. Optom Vis Sci. 2020;97(1):3–8. https://doi.org/10.1097/OPX.0000000000001465

39. McCullough SJ, Doyle L, Saunders KJ. Intra- and inter- examiner repeatability of cycloplegic retinoscopy among young children. Ophthalmic Physiol Opt. 2017;37:16–23. https://doi.org/10.1111/opo.12341

40. Zadnik K, Mutti DO, Adams AJ. The repeatability of measurement of the ocular components. Invest Ophthalmol Vis Sci. 1992;33:2325–2333.

41. Walline J, Kinney K, Zadnik K, Mutti DO. Repeatability and validity of astigmatism measurements. J Refract Surg. 1999;15:23–31.

42. Jorge J, Queiros A, Almeida J, Parafita M. Retinoscopy/autorefraction: Which is the best starting point for a noncycloplegic refraction?. Optom Vis Sci. 2005;82(1):64–68.

43. Rotsos T, Grigoriou D, Kokkolaki A, Manios N. A comparison of manifest refractions, cycloplegic refractions and retinoscopy on the RMA-3000, autorefractometer in children aged 3 to 15 years. Clin Ophthalmol. 2009;3:429–431. https://doi.org/10.2147/OPTH.S5145

44. Hardiyanti D, Dyah NAF. Correlation between Autorefractometry and retinoscopy with subjective refraction in refractive error patients at Dr Kariadi Hospital, Semarang. Ophthalmol Indonesiana. 2021;47(2):46–51. https://doi.org/10.35749/journal.v47i2.100302

45. Aboumourad, R, Anderson, H. Comparison of dynamic retinoscopy and autorefraction for measurement of accommodative amplitude. Optom Vis Sci. 2019;96(9):670–677. https://doi.org/10.1097/OPX.0000000000001423

46. Morton A, Barrett J. A clinical investigation of the merits of various methods of practicing retinoscopy. Br Med J. 1886;1(1307):105–108. https://doi.org/10.1136/bmj.1.1307.105