

# Article • Subjective Comparison Between Dyop and Snellen Refractions

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**Conclusions:** Subjective refractions with a Dyop chart were comparable to a Snellen chart. The efficiency of a Dyop refraction, however, was typically twice that of the Snellen chart, with a narrower variance in visual acuity measurements and an improved level of acuity of about 0.25 diopters.

**Keywords:** Dyop acuity chart, Snellen acuity chart, subjective refraction, visual acuity

## ABSTRACT

**Background:** A Dyop (or dynamic optotype) is a spinning visual target which uses the strobic detection of the spinning gaps/segments of the ring to measure visual acuity.

**Methods:** Forty subjects with visual acuity better than 6/12 (20/40) and ages between 20 and 28 years ( $24.48 \pm 2.01$  years) were recruited at the University of Benin Optometry Clinic. Snellen and Dyop acuity charts were displayed on a monitor at a distance of 6 meters. The assessment sequence between the two acuity chart formats was alternated for every other patient to reduce potential refractionist bias. Subjective refraction was measured in both eyes, and the duration of testing for each patient and each method was recorded.

**Results:** There was no significant mean Thibos notations difference, M ( $p = 0.77$ ), J0 ( $p = 0.27$ ), and J45 ( $p = 0.57$ ) using the Bland-Altman plot and 95% limits of agreement between the two charts, and there were no differences as to age or gender. There was, however, a disparity in the mean acuity of about 0.25 diopters with the mean Snellen acuity of  $1.60 \pm 0.21$  decimal units and the mean Dyop acuity of  $1.17 \pm 0.14$  decimal units with a linear relationship:  $y = 0.3121x + 0.6709$  ( $p = 0.00$ ). The refraction with a Dyop acuity chart also typically took half as long ( $339 \pm 122$  seconds) as the refraction with a Snellen acuity chart ( $680 \pm 281$  seconds),  $p = 0.00$ .

## Introduction

According to the World Health Organization, uncorrected refractive errors such as myopia, hyperopia, and astigmatism resulting in blurred vision represent the leading cause of visual impairment world-wide, followed by cataracts (33%).<sup>1</sup> Recent research done<sup>2</sup> reveals that uncorrected refractive error is the most frequent cause of moderate and severe visual impairment (MSVI). Uncorrected refractive errors worldwide affect 52.9% of people. An estimated 19 million children are visually impaired, out of which 12 million have impairment due to refractive error.<sup>3</sup>

Measurements of refractive error and visual acuity are probably the most common assessments made by an optometrist to identify visual system abnormalities such as disorders of the ocular media, optic nerve, and visual pathway.<sup>4</sup> Subjective refraction uses comparative lenses (such as sphere, cylinder, axis, and/or prism) to derive the dioptric lens combination that will result in maximum visual acuity.

The ability of the eye to focus and to see an image clearly is dependent on several structures within the eye. The focusing power of the lens and cornea must correspond appropriately to the length of the eye so that the light rays ultimately come to a focal point at the retina. If the full spectrum of rays of light focuses either in front of or behind the retina, the image will not be as clear as possible, due to the presence of refractive error.<sup>5</sup>

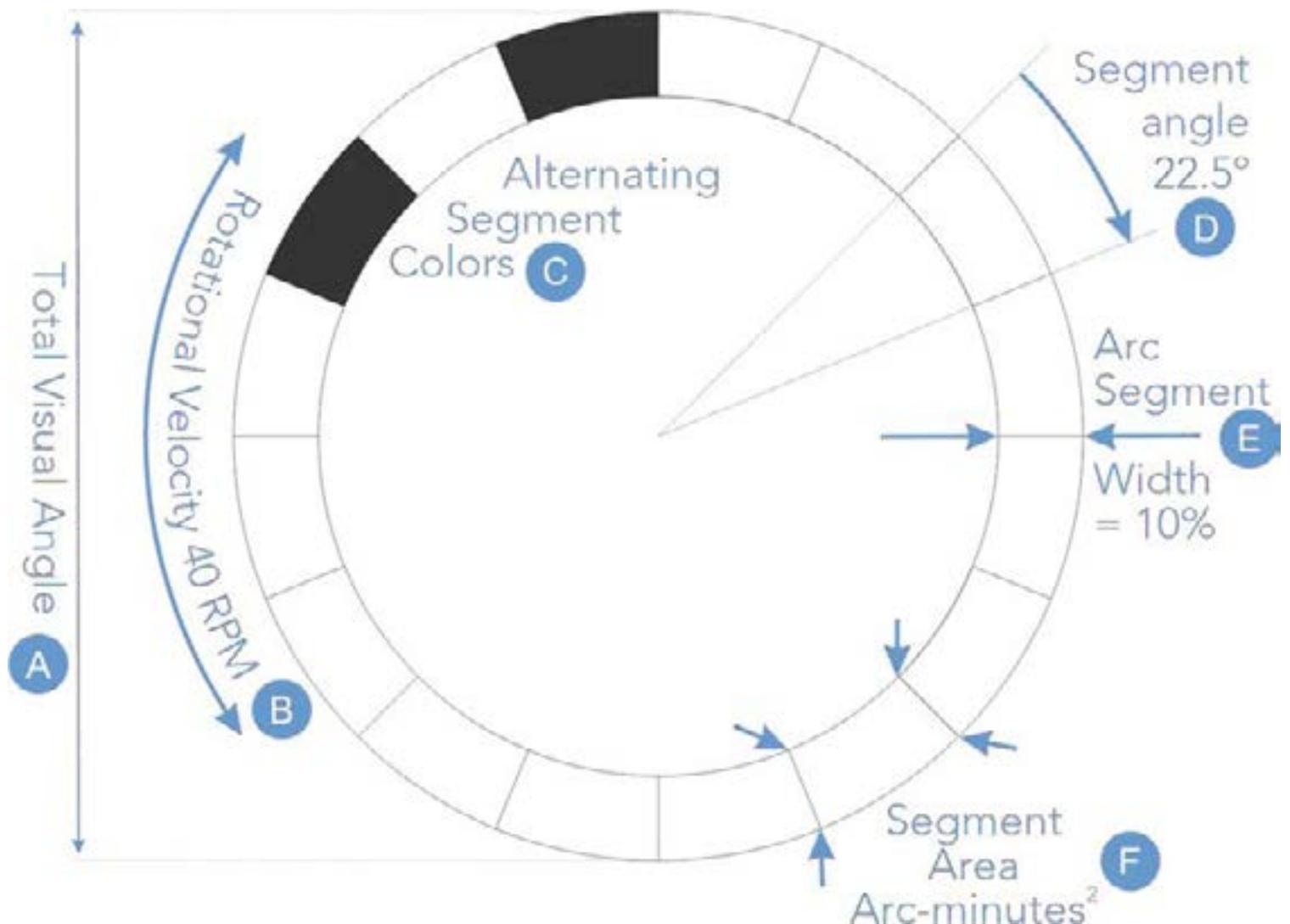
Visual acuity measurements are commonly done in routine oculo-visual assessments and usually involve patients reading letters, numbers, or picture charts presented at a specific distance (far and near). The patients begin reading the targets that are easier for

them to see, and these decrease in size. This routine has been standardized to follow a reasonable step-by-step procedure and can be evaluated under monocular or binocular subjective refraction conditions at a relative far or near distance. The different test charts (printed, projected, or displayed on a computer screen) contain different optotypes (letters, numbers, symbols) and can be performed using a trial frame or phoropter.<sup>6</sup> The patient continues to read/identify the targets until they are no longer able to resolve them or until a stopping rule is fulfilled (usually if the patient incorrectly identifies a certain number of targets per line). Furthermore, to increase the probability of increasing the test precision and consistency, the tests should be rapid, easily administrable, and cost-effective.<sup>7</sup>

Colenbrander<sup>8</sup> commented, per the International Council of Ophthalmology Visual Functions Committee, that as “deficiencies are periodically revealed and need correction, new developments in tests are

occurring, etc. Thus, a standard may be an evolving document and needs to be reviewed periodically and should not be regarded as immutable.” The standardization of the Snellen test in 1984 with the “Consilium Ophthalmologicum Universale Visual Acuity Measurement Standard” provided a benchmark as a global visual acuity standard. However, it also predicted that technical improvements might obviate the use of static letters and other optotypes as to acuity and refraction measurement.

In 1862, Dr. Herman Snellen developed and copyrighted a visual target using European-style letters as a more precise assessment of refractive error. The Snellen chart consists of multiple rows of letters and is typically completed at a testing distance of 6 meters (20 feet) in order for each letter on the 6/6 (20/20) Snellen visual acuity line to subtend a visual angle of 5 minutes of arc.<sup>9</sup> The letters are typically larger at the top of the chart and gradually decrease in size for each row as the patient continues to read down the chart.



**Figure 1.** This illustrates the fundamental features of the Dyop (dynamic optotype) acuity chart. The total circular diameter or visual angle (A), speed of rotation (B), contrasting colors in black and white (C), segment angle (D), segment arc width (E), and area of each segment in minutes of arc (F).<sup>11</sup>

Printed, projected, and computerized versions of the Snellen chart are available. Printed paper charts or projected charts have the disadvantage of being easily memorized, as clinicians are unable to present the letters in a random order. With the advancement of technology over the past few decades, computerized visual acuity chart systems have become popular among clinicians as they allow for a larger visual acuity range to be tested, smaller incremental line displays, single- or multiple-target presentations, and the use of a variety of optotypes: Snellen-type letters, ETDRS charts (logMAR), Landolt Cs (or rings), tumbling Es, numbers, children's symbols (Allen figures), HOTV charts, or LEA symbols.<sup>10</sup>

In 2008, Allan Hytowitz discovered that a uniformly spinning segmented ring could provide a strobic visual stimulus as an optotype. That binary strobic dynamic optotype, or Dyop, had distinctive properties in that a combination of variables, such as the ring diameter (angular arc width), gap/segment stroke width, rotation speed (rotations per minute), gap/segment contrast, and gap/segment colors, combine with the strobic pixelized refresh rate of the photoreceptors to create an indicator for visual acuity and the functional parameters for determining refractions (Figure 1). Because Dyop acuity and refractive measurement is not dependent upon cultural cognition of letters, the Dyop can also be used for infants and non-literate or non-verbal individuals as a more accurate measure of acuity. Unlike static optotypes, which get increasingly blurry as they get smaller or further away, a spinning/rotating Dyop has a significantly sharper threshold as to the acuity endpoint based upon the angular arc width and viewing distance.<sup>11</sup> The circular Dyop segmented ring typically comprises 8 black and 8 white equally sized, alternating segments on a neutral gray background, spinning at 40 rotations per

minute, with a 10% gap/segment stroke width.<sup>12</sup> Since photoreceptors require a change in stimulus to evoke an excitatory response, a kinetic optotype such as a Dyop may more favorably match the visual response mechanism than static optotypes, which use small eye motions (saccades) to help refresh the photoreceptors.

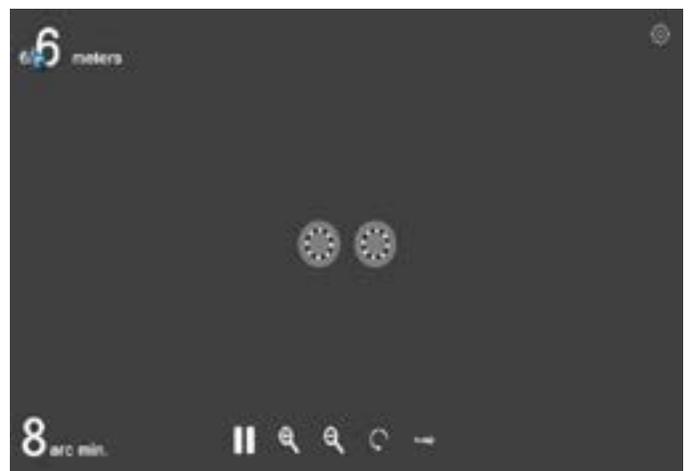
In this study, an effort was made to evaluate the agreement and/or possible disparity of refractive error measurement between a Dyop and a Snellen acuity chart in adults (Figure 2). This may provide a solution to the visual and cognitive variance experienced by patients reading multiple-line steps of letter charts during acuity and refractive error measurements. The dependence of such charts on letter-based literacy has resulted in calls for a better tool for providing visual acuity assessment. This study evaluates the findings of subjective refraction obtained using dyop and Snellen acuity charts.

### Patients and Methods

Ethical clearance was obtained from the Ethical Committee of the Department of Optometry, University of Benin for an experimental study involving a total number of 40 subjects whose ages ranged between 19 and 28 years, whose habitual visual acuity was better than or equal to 6/12, and who were free of all ocular and systemic diseases that have significant effect on vision. Subjects were recruited at the University of Benin Optometry Clinic, Ugbowo, Benin City between July and August 2018.

### Static Retinoscopy

Retinoscopy was performed at arm's length, with the eyes focusing on the distant optotype targets. The non-tested eye was occluded. The room illumination was reduced to obtain a high-contrast view of the reflex. The examiner was seated in front of the tested eye.



**Figure 2.** Comparison of Snellen and Dyop acuity chart. Source: Chart2020® Version 10.3.6 Computerized Visual Acuity Unit

The patient was instructed to report if the view of the non-tested eye was obstructed and was asked to focus on the distant target at all times. A phoropter or a trial frame with appropriate spherical and cylindrical lenses from a trial lens set was used to reach neutrality. The dioptric working distance of +1.50 D was subtracted from the neutralizing lens to obtain the refractive error of the eye.

### **Subjective Refraction Using Snellen Acuity Chart**

Following Borish and Benjamin,<sup>13</sup> the subjective refraction was achieved with this procedure:

- i. Unaided visual acuity was assessed and recorded.
- ii. With the data for sphere and cylinder obtained from net retinoscopic findings before the patient's eyes, the patient was asked to read the chart from the top and sequentially down, one line at a time. The visual acuity with the retinoscopic findings was recorded.
- iii. The patient was fogged to maintain accommodation in a relaxed state.
- iv. The spherical power was adjusted in  $\pm 0.25$  D steps subjectively to obtain best visual acuity, using maximum plus or minimum minus.
- v. Jackson cross cylinder was used to refine the cylindrical axis and power in order to determine the astigmatic correction in the right eye where necessary or applicable.
- vi. The spherical power was refined subjectively using duochrome to get the monocular spherical endpoint for the right eye.
- vii. The subjective refraction results and VA for the right eye were recorded in decimal units.
- viii. The steps (i – vii) above were repeated for the left eye.
- ix. Binocular balancing was carried out using alternate occlusion, after fogging both eyes, to arrive at equal accommodative state with maximum plus or minimum minus.
- x. Both eyes were uncovered to check for binocular visual acuity.
- xi. The final prescription obtained and the time taken was recorded.

### **Subjective Refraction Using Dyop Acuity Chart**

These were the steps taken to determine the subjective refraction endpoint using the Dyop acuity chart:<sup>14</sup>

- i. Unaided visual acuity was assessed and recorded.
- ii. With the data for sphere and cylinder obtained from net retinoscopic findings, the threshold spinning

Dyop arc width seen was recorded as visual acuity for retinoscopic findings.

- iii. The patient was fogged to maintain accommodation in a relaxed state.
- iv. The spherical power was adjusted subjectively in  $\pm 0.25$  D steps to obtain best possible visual acuity, using maximum plus or minimum minus.
- v. Jackson cross cylinder was used to refine the final in the right eye.
- vi. The spherical power was refined subjectively using duochrome to achieve optimum clarity and the monocular spherical endpoint for the right eye.
- vii. The Dyop arc minute angular diameter was reduced to where the smallest spinning Dyop arc minute diameter could still be detected to determine the refraction endpoint.
- viii. Rotation, location, and direction of the spinning Dyop was alternated to check for false positives.
- ix. The subjective refraction results and VA for that eye (OD) were recorded in decimal units.
- x. The steps (i – ix) above were repeated for the left eye.
- xi. Binocular balancing was carried out using alternate occlusion, after fogging both eyes, to arrive at equal accommodative state with maximum plus or minimum minus.
- xii. Binocular visual acuity was assessed and recorded.
- xiii. The final prescription obtained and the time taken for the procedure was recorded.

### **Snellen or Dyop Comparative Tests Sequence**

Because the attributes of the optotypes for the two acuity charts are significantly distinctive, it was difficult for subjects not to differentiate as to which target type was being used. To compensate for the selection difference, the Dyop/Snellen sequence of the two comparative tests was alternated with each patient.

### **Thibos Notations**

Power vectors are the geometrical substitute of the classical sphero-cylindrical notation or refractive errors by a new 3-tuple of orthogonal values (M, J<sub>0</sub>, J<sub>45</sub>).<sup>15</sup> According to Thibos, Wheeler, and Horner, the first component in the notations is a spherical lens with power M equal to the spherical equivalent of the given refractive error (Sph + Cyl/2) and two Jackson crossed cylinder (JCC) lenses, one at 180° with power J<sub>0</sub> = (Cyl/2) cos2 $\beta$  and the other at axis 45° with power J<sub>45</sub> = (Cyl/2) sin2 $\beta$ , as the astigmatic decomposition of the polar form of astigmatism in the refractive error.

These three independent components (M, J0, and J45) represent refractive error. In addition, power vectors may be less abstract and more familiar to clinicians compared to other more complex formalisms such as matrix methods or wave-front refraction. In summary, Thibos notation has become a useful tool for the theoretical and clinical management of refractive error.

### Data Collection and Statistical Analysis

This study was analyzed using Statistical package for Social Science version 25.0:

- i. Duration of testing with each method was recorded.
- ii. The differences between the findings obtained using the two acuity charts were determined with a one sample t-test.
- iii. The efficiency in measuring with both acuity charts was also observed to determine significance.

### Results

Forty subjects were recruited into this study, aged  $24.48 \pm 2.01$  years; 40% (16 subjects) were females aged  $24.00 \pm 1.93$  years, and 60% (24 subjects) were males aged  $24.79 \pm 2.04$  years. The inter-ocular difference in refractive error (M, J0, and J45) measurement for age range and gender, using Snellen acuity and Dyop acuity charts, was not statistically significant (Tables 1 & 2).

The line plot of binocular visual acuity measurements was obtained with the two charts in decimal notation, in which linear trend lines represent best-fit straight line for Snellen and dyop acuity charts (Figure 3). The slope of Dyop ( $1.17 \pm 0.14$  decimal units) acuity was steeper than the slope of Snellen ( $1.60 \pm 0.21$  decimal units), which indicates that a dyop acuity chart is more stable, more reliable, and with less statistical variance ( $s^2 = 0.02$ ) in visual acuity assessment as compared to a Snellen acuity chart ( $s^2 = 0.05$ ).

The trend of the relationship between the binocular visual acuity scores in decimal notations obtained for the subjects using the two charts is shown in Figure 4. The trend line represents the linear relationship between the two charts, x represents the Snellen coefficient, y represents the Dyop coefficient, and R2 (0.23) is the coefficient of determinacy, which indicates how best the line fits ( $p = 0.00$ ). This indicates that there is a weak relationship between the two charts in binocular visual acuity assessment. The relationship was explained by the regression model:  $y = 0.3121x + 0.6709$ , indicating that binocular visual acuity assessment done with Snellen was exaggerated by  $\leq 0.05\%$  as compared to binocular visual acuity assessment done with Dyop acuity.

**Table 1. Subjective Refraction findings for Snellen and Dyop Acuity Charts** (Descriptive statistics results for the subjective refraction assessments are presented using the right eye only since the inter-ocular difference as to the subjective refraction assessments with Snellen acuity and Dyop acuity charts were not statistically significant (Appendix I).)

Parameters	N	Snellen		Dyop	
		Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
M Components	40	$-0.04 \pm 0.25$	-0.62 – 0.50	$-0.04 \pm 0.21$	-0.62 – 0.50
J0 Components	40	$-0.01 \pm 0.23$	-0.25 – 1.25	$0.01 \pm 0.23$	-0.29 – 1.25
J45 Components	40	$-0.02 \pm 0.08$	-0.32 – 0.11	$-0.02 \pm 0.07$	-0.24 – 0.11
Binocular VA	40	$1.60 \pm 0.21$	1.00 – 2.00	$1.17 \pm 0.14$	1.00 – 1.50
Time Taken	40	$680.28 \pm 281.24$	310.00 – 1700.00	$338.93 \pm 121.90$	185.00 – 641.00

**Table 2. Snellen Acuity Chart versus Dyop Acuity Chart in Subjective Refractive Findings** (One sample t-test results for refractive error (M, J0, and J45) assessment were presented using the right eye only since the inter-ocular difference as to the subjective refractive assessments with Snellen acuity and Dyop acuity charts were not statistically significant.)

Parameters	N	Mean Difference (Bias) $\pm$ SD	Lower Limit of Agreement	Upper Limit of Agreement	p - value
Spherical Equivalent (M Component)	40	$0.01 \pm 0.12$	-0.22	0.24	0.77
J0 Components	40	$0.00 \pm 0.03$	-0.05	0.05	0.27
J45 Components	40	$-0.00 \pm 0.01$	-0.03	0.02	0.47
Binocular VA	40	$0.43 \pm 0.19$	0.37	0.49	0.00
Time taken for Subjective Refraction	40	$341.35 \pm 197.46$	278.20	404.50	0.00

LINE PLOT FOR BVA MEASUREMENTS USING THE TWO CHARTS FOR THE SUB JECTS

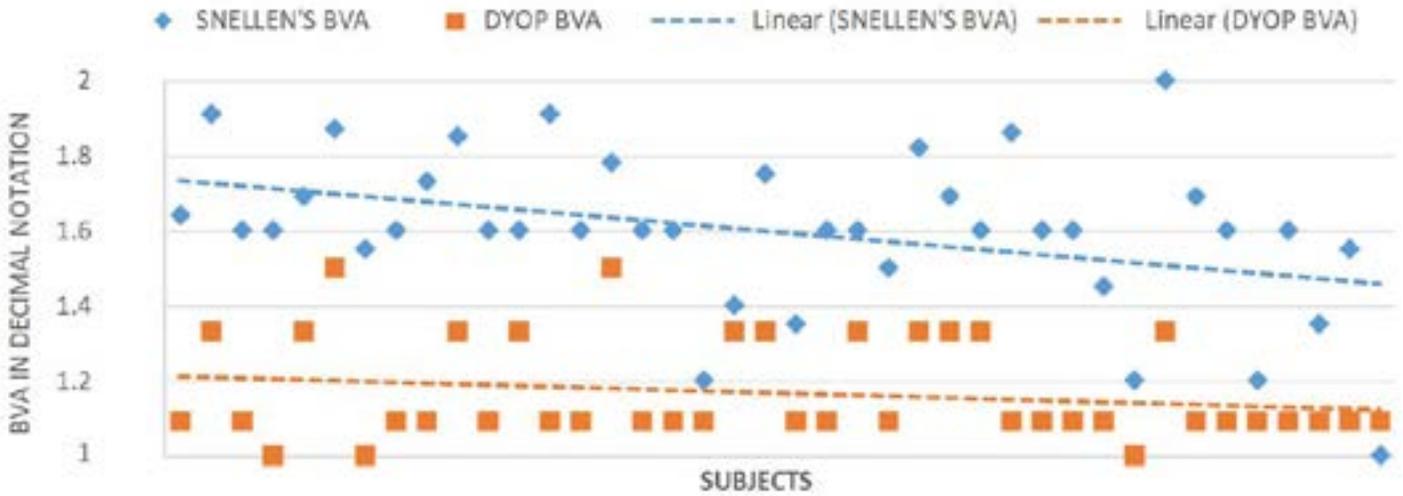


Figure 3. Binocular visual acuity scores in decimal notation for the subjects using the two charts

COMPARISON OF BINOCULAR VISUAL ACUITY ESTIMATED WITH DYOP AND SNELLEN ACUITY CHARTS FOR THE SUBJECTS

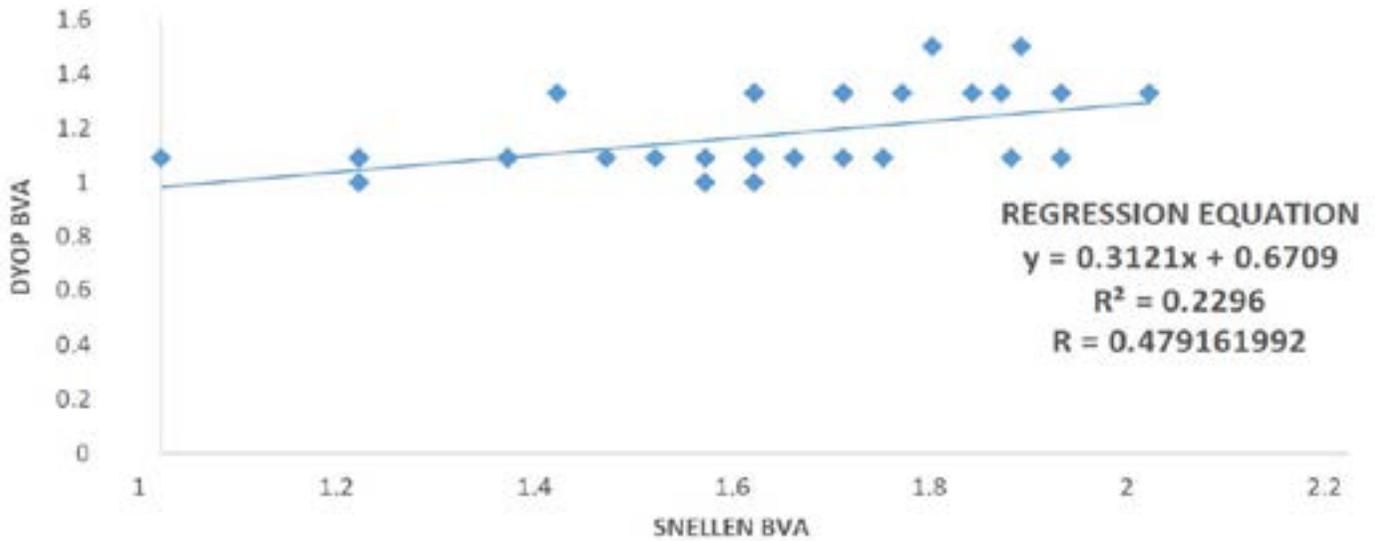


Figure 4. Relationship between the binocular visual acuity scores obtained with the two charts

COMPARISON OF TIME TAKEN FOR SUBJECTIVE REFRACTION WITH DYOP AND SNELLEN ACUITY CHARTS FOR THE SUB JECTS

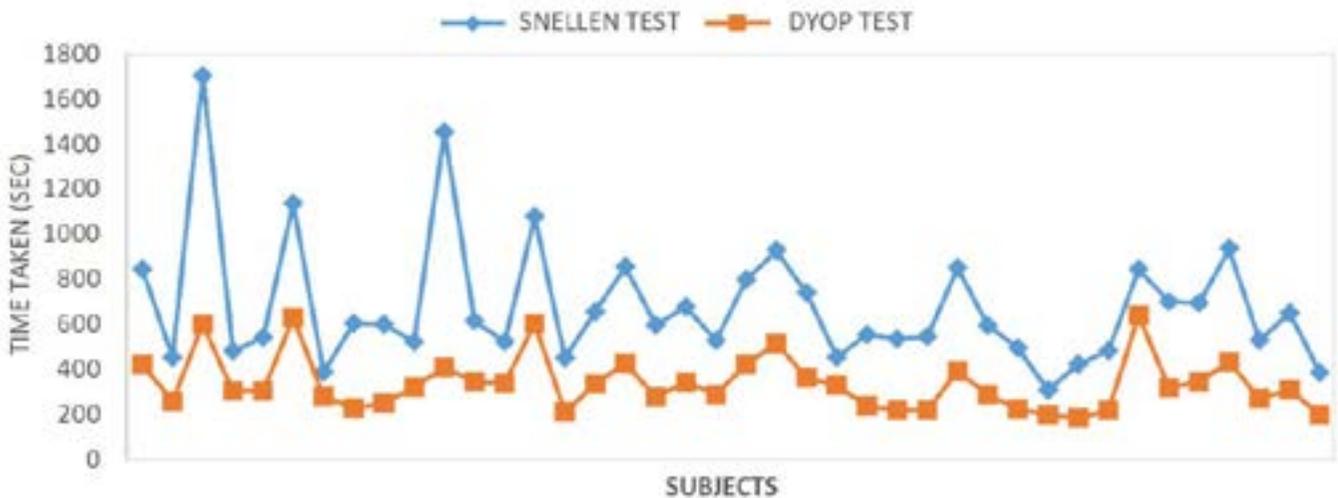


Figure 5. Disparity of the time taken for subjective refraction with the two charts

Figure 5 is a graph of disparity for the two tests (subjective refraction with Snellen acuity and Dyop acuity charts) as it relates to the time taken. This showed marked significant difference ( $320 \pm 183$  seconds,  $p = 0.00$ ), indicating that the difference could not have occurred by chance. The time taken for the Dyop acuity test ( $339 \pm 122$  seconds) was half the time taken for the Snellen test ( $680 \pm 282$  seconds), which implies that the Dyop acuity chart is more efficient in the assessment of subjective refraction compared to the Snellen acuity chart.

## Discussion

The results of this study showed that a Snellen acuity chart and a Dyop acuity chart are similar in binocular refractive error measurements but distinctive in binocular visual acuity assessment and efficiency in subjective refraction. The Snellen mean binocular visual acuity assessment was higher (exaggerated) than when using a Dyop acuity chart. The refractive error difference between the two charts was not statistically significant (M:  $0.01 \pm 0.12D$ :  $p = 0.77$ , J0:  $0.00 \pm 0.03D$ :  $p = 0.27$ , and J45:  $-0.00 \pm 0.01D$ :  $p = 0.47$ ), but binocular visual acuity difference between the two charts was  $0.43 \pm 0.19$  decimal units. This represents more than a two-line difference ( $p = 0.00$ ) and improved level of acuity of about 0.25 diopter with a narrower variance ( $1.17 \pm 0.14$  decimal) when compared with that of the Snellen acuity chart ( $1.60 \pm 0.21$  decimal units). The efficiency of the Dyop test ( $339 \pm 122$  seconds) was twice that of the Snellen test ( $680 \pm 282$  seconds).

The disparity in the Snellen visual acuity assessment may be due to the design features of the Snellen chart, as already mentioned,<sup>9</sup> ranging from the rows of letters of dissimilar length, irregularity and arbitrary progression of letter sizes between lines leading to overestimation of vision at the lower end of acuities, letters of unequal legibility, and large test-retest variability ( $\pm 5$  to 16.5 letters in normal subjects). The Snellen acuity measurement is more reliant on the observer's cognitive and recognition ability and communication skills.<sup>16</sup> This was also in agreement with the study<sup>17</sup> that observed that measuring recognition acuity by reading letters may lead to an overestimation of visual ability through the inclusion of top-down cognitive processes that are unavailable for resolution tasks.

The time disparity for binocular refractive error measurements using the two charts may be due to the more precise Dyop threshold endpoint, which reduced the unreliable responses observed with the

use of line steps of multiple letter charts, and the ease of the Dyop endpoint detection by the subjects. Because photoreceptors require a change in stimulus to evoke an excitatory response, a kinetic optotype (Dyop) may more favorably match the nature of the photoreceptor response mechanism than a static optotype in which small eye motions help tease out the visual responses.<sup>9</sup> The comparative guess rate may also influence the efficiency of the tests where there is a known choice of two possibilities for the Dyop acuity chart (clockwise or counter-clockwise), while there are essentially 26 possibilities of the letter targets as the subjects are unaware of the limited selection of letters.<sup>18</sup>

Sum and Woo<sup>19</sup> evaluated the agreement of refractive error measurement between a Dyop acuity chart and a LogMAR "E" acuity chart using 40 participants aged  $45.3 \pm 12.6$  years with visual acuity better than 6/12. The subjective refractive findings obtained adopting Thibos (1997) notations (M, J0, and J45) to represent power vectors shows that there was no significant mean difference of M, J0, and J45 measured between the two charts using the Bland-Altman plot with 95% limits of agreement ( $p > 0.05$ ). The correlations between the difference of measurements are as follows: mean of M ( $p = 0.97$ ), J0 ( $p = 0.386$ ), and J45 ( $p = 0.225$ ), which established no significance. Hence, subjective refraction findings obtained with the use of a digital dynamic spinning optotype (Dyop) were comparable to the traditional LogMAR "E" chart.

Sum and Woo<sup>20</sup> previously investigated the use of a Dyop acuity test in measuring visual acuity using 40 participants with mean age  $69.5 \pm 5.9$  years and with mean LogMAR visual acuity of  $0.28 \pm 0.17$ . The visual acuity measured by the dynamic optotype was comparable to the traditional logMAR chart; however, 70% of the subjects preferred the use of the Dyop test versus 23% of subjects who preferred to use the Snellen and logMAR E test.

Harris and Keim<sup>11</sup> investigated the accuracy of the dyop acuity test with 162 participants by assessing the threshold acuities on a fully randomized basis, using Sloan letters and Dyop doublet with the following test conditions: uncorrected refraction and corrected refraction with +2.00 lens, +3.00 lens, +4.00 lens. There was a very strong linear Pearson correlation between Sloan and Dyop acuity measures, with all the test conditions for the subjects (Pearson  $r = 0.95$ ;  $p < 0.001$ ). The statistical variance in visual acuity measurement with the study condition revealed 0.193 and 0.035 for a projected Sloan and

a Dyop doublet, respectively. The Dyop was reported to be advantageous due to the speed at which the threshold acuity endpoint is defined, its finer acuity granularity as compared to the typically used acuity “line” steps, and its ease of endpoint identification by the subjects. The 2015 Dyop doublet was also found to be simpler to use, easier in eliminating unreliable responses, and had less variance than the 2013 prototype Dyop triplet. The linear increase in Dyop acuity endpoint angular diameter with an increase in blur for the 2015 Dyop doublet was also smaller than the 2013 prototype Dyop triplet. The linearity of the Dyop angular width with increased blur, versus the classical Snellen logarithmic increase, is likely due to the Dyop having a smaller gap/segment stimulus area of 0.54 arc minutes squared versus the averaged (theoretical) Snellen gap stimulus area of 1.00 arc minute squared. The logarithmic disparity directly correlates to the Snellen gap being twice the actual, and empirically measured, gap of the Dyop test, as well as contributing to the higher variance of the Snellen test to the variance of the Dyop test.

Harris and Keim<sup>21</sup> previously investigated the accuracy of the Dyop triplet acuity chart using 150 participants. They tested threshold visual acuity on standard eye charts, which includes projected Sloan and the older Dyop triplet. The targets were presented as standard projected chart letter targets viewed on a halogen projector to a silvered screen setup, or directly viewed on a computer monitor (M&S Technologies Smart System II visual acuity system), or as a Dyop acuity chart viewed on a computer monitor. The disparity in the acuity endpoint for the projected Snellen versus the computer-generated Snellen test indicates that the “fuzzier” projected optotypes may contribute to an unintentional and inherent overcompensation in wanting the projected optotypes to be “crisper.” The lens power conditions were full correction alone and then with the following lenses placed over their habitual correction: +2.00 OU, +3.00 OU, +4.00 OU, and two Bangerter filters (0.6 and 0.2). The order was randomized by chart, and within the chart, by lens condition. Results obtained show that plus lens blur does not decrease visual acuity to the same degree on the Dyop target as on the M&S computer-based chart or as on the projected chart. The statistical variance in visual acuity measurement with the study condition revealed  $s^2 = 0.282$ , but only 0.060 for a projected Sloan and Dyop triplet.

## Conclusions

This research project validates that a Dyop acuity chart is comparable to the Snellen acuity chart in refractive error measurement with a significantly greater efficiency and less cognitive variance in visual acuity measurements and an improved level of acuity of about 0.25 diopter. The Dyop concept may be a tool that can revolutionize the understanding of visual perception and provide a better assessment of visual function.

## Recommendations for future study

1. Comparison between findings of subjective refraction with different age groups should be done using a Dyop acuity chart and other charts, such as the Landolt C, ETDRS, and so on.
2. Other visual function parameters like colour vision and contrast sensitivity should be explored with the Dyop concept.
3. Assessment of the visual acuity of subjects with ocular conditions like glaucoma, ARMD, or amblyopia with a Dyop acuity chart in comparison with other charts should be performed.
4. Assessment of the efficacy of a Dyop acuity chart on binocularity tests, fusion tests, and so on would be interesting to unravel the unperceived capabilities.

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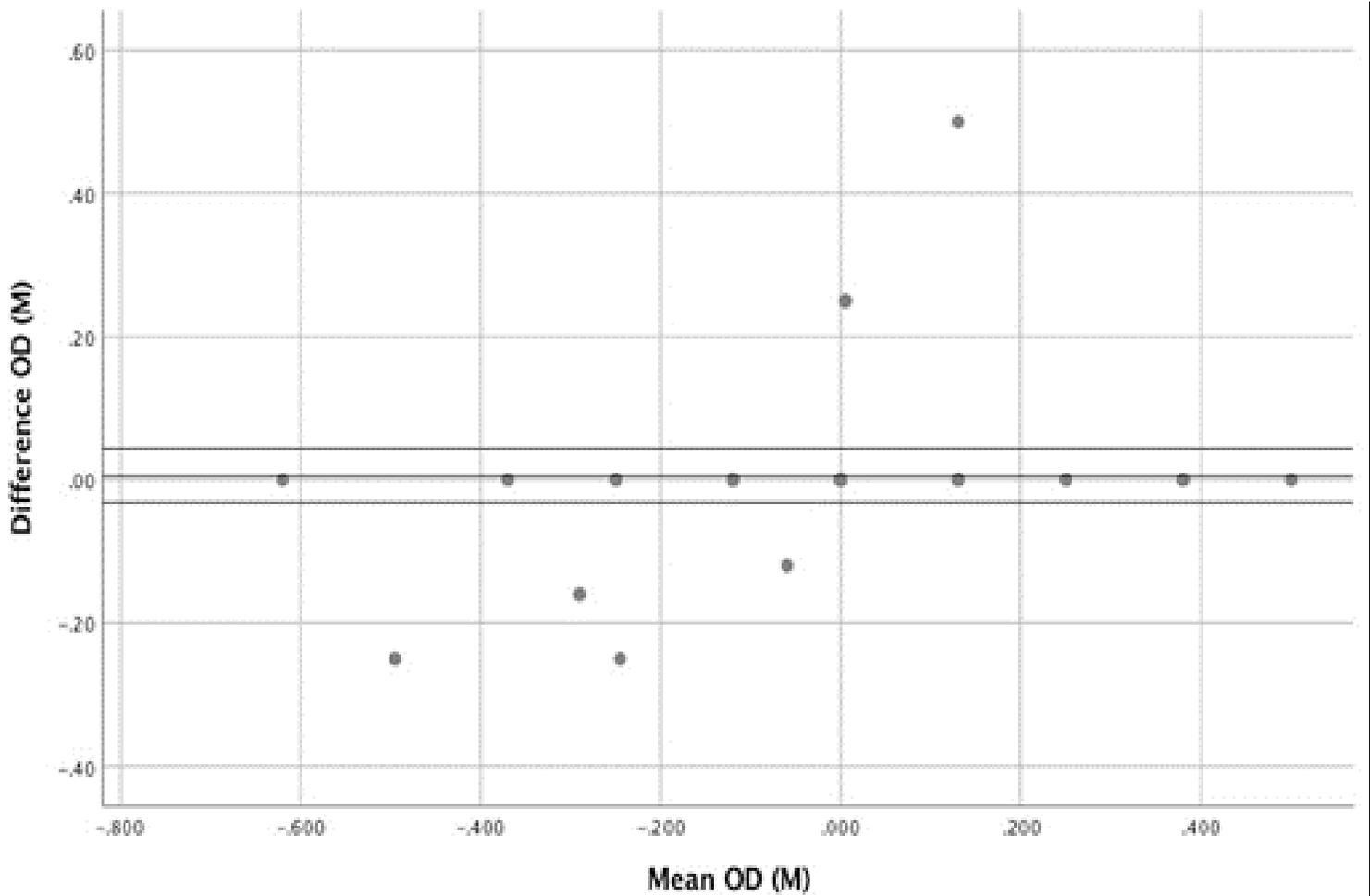
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## APPENDIX I

Age groups and gender distribution of subjects with mean difference (bias) observed in parameters for refractive error measurements with the two charts using paired t-test. The inter-ocular differences in refractive error (M, J0, and J45) measurement for age range and gender, using Snellen acuity and Dyop acuity charts, were not statistically significant, as shown in the table above. Standard deviation and p-value were not computed for age group 19-20 years because the sum of the case weight is  $\leq 1$ .

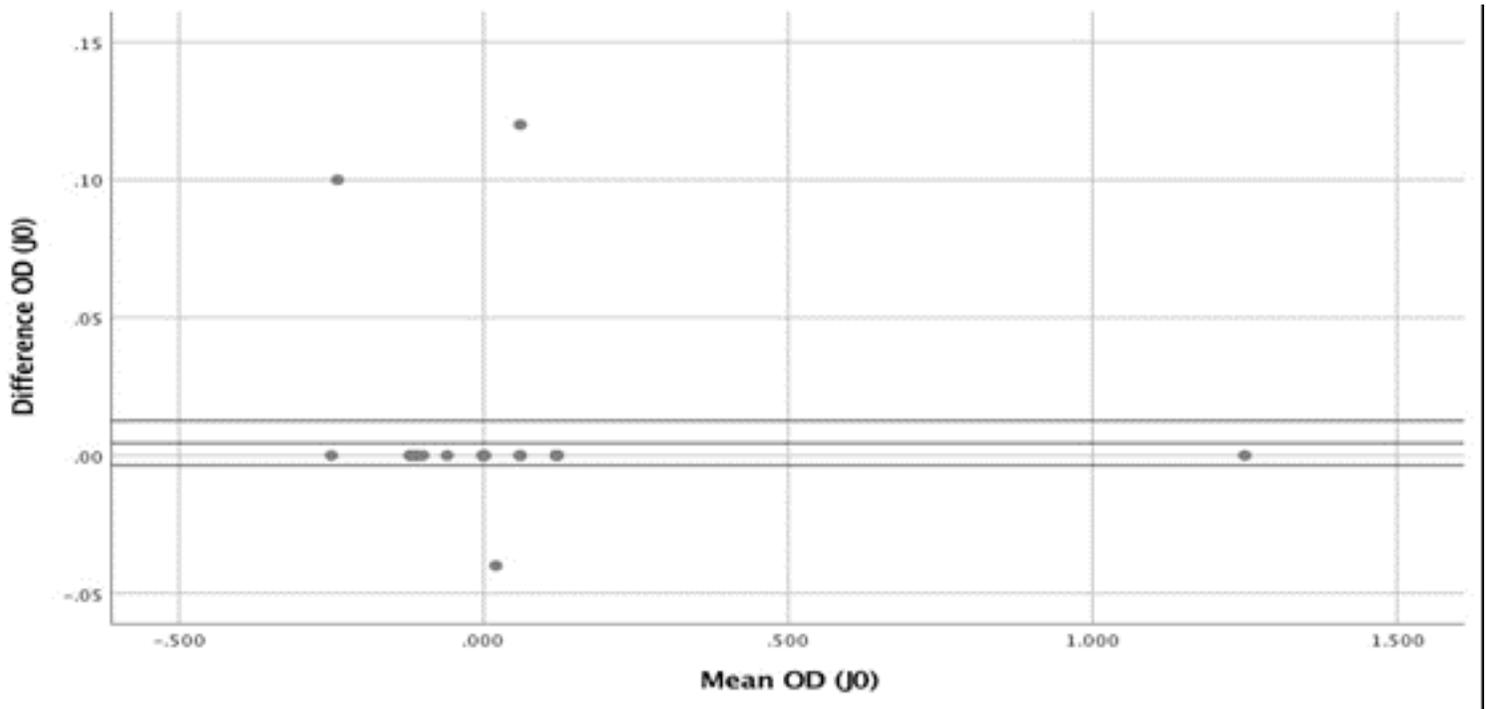
Age Group	N (%)	Parameters	Mean difference ± SD	p-value	Level of Significance
19-20	1 (2.5%)	M (OD) and M (OS)	0.00		
		J0 (OD) and J0 (OS)	0.00		
		J45 (OD) and J45(OS)	0.00		
21-22	7 (17.5%)	M (OD) and M (OS)	0.06 ± 0.15	0.31	Not Significant
		J0 (OD) and J0 (OS)	-0.16 ± 0.24	0.13	Not Significant
		J45 (OD) and J45(OS)	-0.06 ± 0.11	0.21	Not Significant
23-24	10 (25%)	M (OD) and M (OS)	0.03 ± 0.13	0.45	Not Significant
		J0 (OD) and J0 (OS)	0.04 ± 0.12	0.53	Not Significant
		J45 (OD) and J45(OS)	-0.00 ± 0.04	0.80	Not Significant
25-26	16 (40%)	M (OD) and M (OS)	0.03 ± 0.13	0.36	Not Significant
		J0 (OD) and J0 (OS)	0.01 ± 0.04	0.32	Not Significant
		J45 (OD) and J45(OS)	-0.01 ± 0.05	0.56	Not Significant
27-28	6 (15%)	M (OD) and M (OS)	0.04 ± 0.25	0.70	Not Significant
		J0 (OD) and J0 (OS)	0.00 ± 0.15	0.97	Not Significant
		J45 (OD) and J45(OS)	0.01 ± 0.19	0.95	Not Significant
<b>Gender</b>					
Female	16 (40%)	M (OD) and M (OS)	0.07 ± 0.16	0.11	Not Significant
		J0 (OD) and J0 (OS)	0.02 ± 0.16	0.63	Not Significant
		J45 (OD) and J45(OS)	-0.02 ± 0.05	0.10	Not Significant
Male	24 (60%)	M (OD) and M (OS)	0.02 ± 0.14	0.53	Not Significant
		J0 (OD) and J0 (OS)	-0.04 ± 0.15	0.21	Not Significant
		J45 (OD) and J45(OS)	-0.11 ± 0.11	0.64	Not Significant

A plot of the agreements in the spherical equivalents (M components) of the right eye



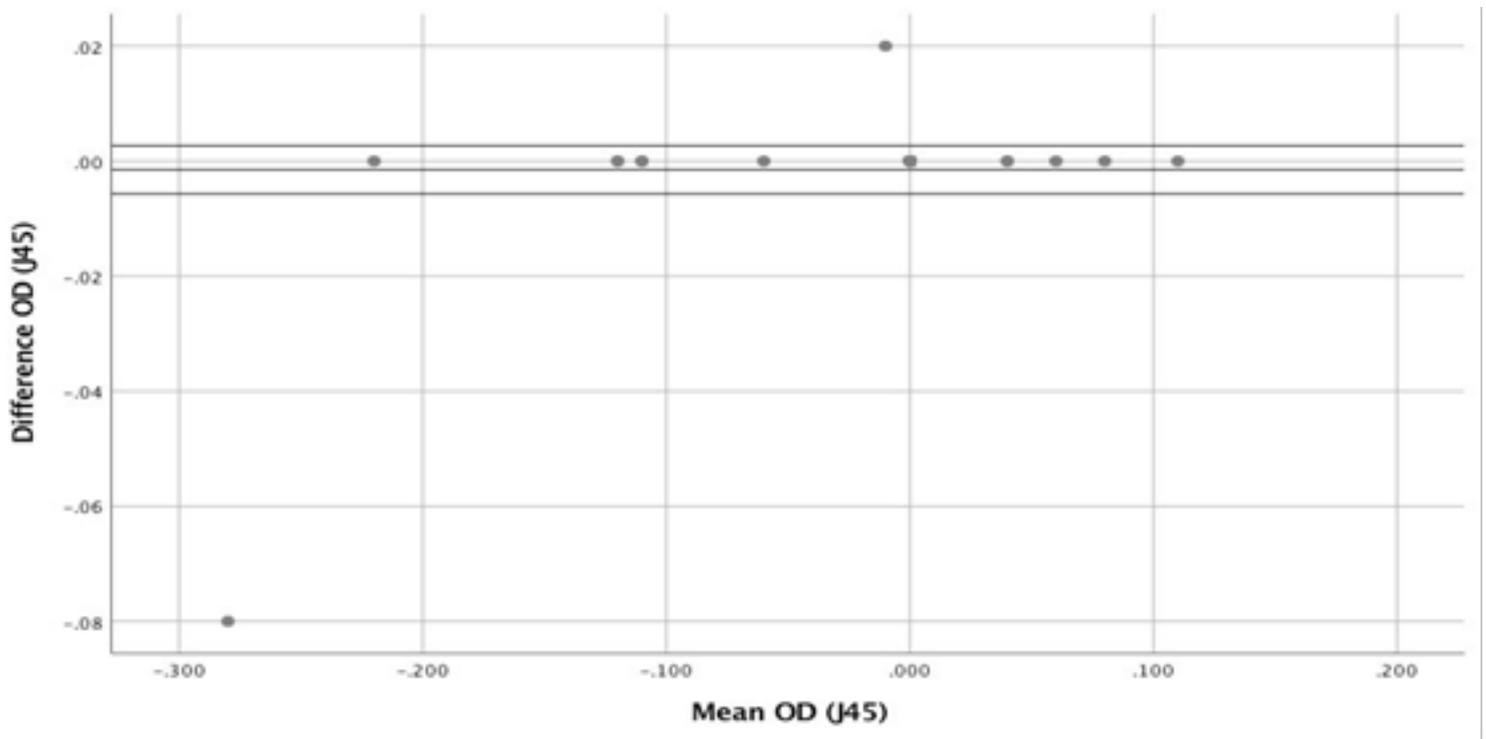
The Bland-Altman plot of difference in means of spherical equivalent findings obtained with the two charts, as a function of the average means of spherical equivalent results, showed that the limit of agreement between the two charts was within 2 standard deviations ( $p = 0.77$ ). The lines represent the mean and two 95% limits of agreement (solid lines). The difference between spherical equivalent measurements of the two charts remains similar across the scatter dots. The plot indicated that there was unbiased limit of agreement between the two charts for the spherical equivalent assessment of the subjects.

A plot of the agreements in the J0 components of the right eye for the subjects



The Bland-Altman plot of difference in means of J0 component assessments obtained with the two charts, as a function of the average means of J0 component results, showed that the limit of agreement between the two charts was mostly within 2 standard deviations ( $p = 0.27$ ). The lines represent the mean and two 95% limits of agreement (solid lines). The difference between spherical equivalent measurements of the two charts remains similar across the scatter dots. The plot also indicated that there was unbiased limit of agreement between the two charts in J0 component findings obtained.

A plot of the agreements in the J45 components of the right eye for the subjects



The Bland-Altman plot of difference in means of J45 component findings obtained with the two charts, as a function of the average means of J45 component findings, showed that the limit of agreement between the two charts was mostly within 2 standard deviations ( $p = 0.47$ ). The lines represent the mean and two 95% limits of agreement (solid lines). The difference between spherical equivalent measurements of the two charts remains similar across the scatter dots. The plot also implied that there was unbiased limit of agreement between the two charts in J45 component findings obtained.