Journal of the Nigerian Association of Mathematical Physics
Volume 56(**March – May *2020 Issue*), pp191 – 200**

REPEATABILITY AND REPRODUCIBILITY OF CONTRAST SENSITIVITY: REACTION TIME TEST USING PELLI- ROBSON CHART.

Akinlabi G.A. and Okoisama A. A.

Department of Optometry, University of Benin, Benin City

Abstract

The purpose of this study was to investigate and quantify the agreements between a new computer based, test for measuring contrast sensitivity (CS) and reaction time(CS test suite) and Pelli- Robson CS chart which is the gold standard for CS measurement. It was carried out by measuring the contrast sensitivity and reaction time for 22 adults between ages 18-30 years, with best corrected distance visual acuity of 6/9 or better and near visual acuity of N5 using the Pelli-Robson chart and the CS test suite. Subjects were tested four times repeatedly for each test and were retested same way, two weeks after their first test date. Data obtained from this study was analysed using Microsoft Excel 2010 with Xlstat statistical plug in. A positive relationship between the Pelli-Robson test and the contrast sensitivity test suite was established. Also, a level of agreement and repeatability between the results gotten from the Pelli-Robson chart and the contrast sensitivity test suite was revealed.

Keywords: Contrast sensitivity, reaction time, Pelli-Robson chart, repeatability, reproducibility.

INTRODUCTION.

Contrast is the difference in luminance or colour that makes an object, an image or a display discernible. A contrast threshold is the smallest amount of contrast required to be able to see a target. Contrast Sensitivity is the reciprocal value of the contrast threshold. Contrast sensitivity can be defined as the ability to discriminate patterns as contrast decreases, in either a visual pathway (determined physiologically) or via the sum of such pathways, as evidenced by whole animal behaviour [1].Assessment of contrast sensitivity has been found to be a. better predictor of an individual's quality of vision and visual performance than visual acuity [2-4].

Reaction time can be defined as the time interval between the stimulus and the initial response[5]. It has previously been defined as the interval between the onset of the stimulus and the response under the condition that the subject has been instructed to respond as rapidly as possible[6].

The Pelli-Robson chart is a large wall-mounted chart, 59 cm wide and 84 cm high, that consists of 16 triplets of Sloan letters 45 each subtending 2.8° at the recommended 1-m test distance, arranged in eight rows of two triplets each. The three letters within each triplet have constant contrast, whereas the contrast across triplets, reading from left to right and continuing on successive lines, decreases by a constant factor ($1/\sqrt{2}$ or 0.15 log unit). The patient reads the letters across and down the chart, as in standard letter acuity measurement. Instead of the letters decreasing in size, however, they decrease in contrast. The final triplet at which the patient reads at least two of three letters correctly determines the log CS, which can be obtained from a score sheet that relates each triplet to a log CS value. This is the manufacturer-recommended scoring method.

In other to effectively identify the relationship between contrast sensitivity measured using the Pelli-Robson chart and the contrast sensitivity test suite, the repeatability and reproducibility of the measurements gotten by these methods have to be ascertained.

To investigate and quantify the agreement between measurements made by two methods, we must at aminimum measure a sample of subjects using both the established measurement method and the newly proposed method. The data from such a study, therefore consist of pairs of measurements from each subject, with the pair containing the subjects' measurements from the two methods.The first step to analyzing such a dataset is to plot the data. The simplest plot is of subjects' measurements from the new method against those from the established method (or vice versa). If both measurements were completely free from error, we would expect the points to lie on the diagonal line of equality. Although it contains the same information as a scatter plot with the line of equality, visual assessment of the disagreements between the measurements from two methods is often more easily done by plotting the difference in a subject's measurements from the two methods against the mean of their measurements, as first suggested by Altman and Bland. Indeed, this is now commonly referred to as the Bland–Altman plot [7].

Our goal is to use the gold standard (Pelli Robson) as a means of comparison of the repeatability and reproducibility of the contrast sensitivity measurement. This contrast sensitivity test suite also measures reaction time.

METHODS

RESEARCH DESIGNS

This was a prospective experimental study which involved healthy male and female subjects. It was carried out at the University of Benin, Department of Optometry, Benin City, Edo state. The research was conducted between 1stJanuary, 2017 and 30thMay, 2017.A simple random sampling method was used for this study.

Corresponding Author**:** Akinlabi G.A., Email: gaakinlabi@hotmail.com, Tel: +2348186146373

The sample size of 22 was gotten from the Sample Size Requirements for Desired 95% Confidence Interval for different Pearson Correlation Values (r), as specified from Sample size estimation for correlations with a pre-specified confidence interval[8].
A total number of 22 subjects comprising of young adults (both males and females) were recruited from the University of Benin, Benin City, Edo state. Ethical clearance was obtained from the local ethics committee in the University of Benin and informed consent was gotten from the subjects. Inclusion criteria were age 18-30 years, distance visual acuity of 6/9 or better and near visual acuity of N5, no medical or ocular conditions that affect contrast sensitivity. Exclusion criteria were children and adults older than 30 years, distance visual acuity less than 6/9 and near visual acuity less than N5,any medical or ocular conditions that affect contrast sensitivity.

DESCRIPTION OF PROCEDURE
This prospective experimental study involved 22 participants. Participants were required to perform a standard visual acuity test using a Snellen test chart and demonstrated a distance visual acuity of 6/9 (or better) and a near visual acuity of N5.
A comprehensive ocular examination using an ophthalmoscope and penlight was done to ensure that ocular diseases which could affect contrast sensitivity were absent and do not interfere with the results.
Contrast sensitivity was measured using the Pelli Robson contrast sensitivity chart. The test distance was 1m and the patient read the letters across and down the chart, as in standard letter acuity measurement. Instead of the letters decreasing in size, however, they decrease in contrast. The final triplet at which the patient reads at least two of three letters correctly determines the log CS. This test was carried out three consecutive times on each eye, and then on both eyes.
Contrast and Reaction time measures were also determined using a specifically designed software known as Contrast Sensitivity Test Suite 0.93. The software was designed by Professor Ian Bailey, Dr. Scott Fitz and Dr.Akinlabi. Measurements were obtained by displaying stimulus types consisting of Numbers, Blinking squares and Jumping squares with varying contrast levels ranging from 0.0 to 2.3. Twenty-four stimuli corresponding to the twenty-four contrast levels were presented per session of the test. The duration of each stimulus was 6000 milliseconds (ms) and the computer was placed at half a meter distance in front of the subject. The test was carried out binocularly and under dim room illumination. Subjects were tested four times for the first test and were retested two weeks after their first test date for four consecutive times also. A single warning tone indicated the commencement of the test and participants clicked on the target presented on the computer screen as soon as it appeared. The software calculated the reaction time (in milliseconds) between the target presentation and target identification by the subject. Participants had a test trial to enable them to adapt to the test and prevent delays in reaction time due to theunfamiliarity of controls.

STATISTICAL TOOLS AND PACKAGE USED FOR DATA ANALYSIS
Microsoft Excel 2010 with Xlstat statistical plugin was used for this analysis

RESULTS
Contrast Sensitivity and Reaction Time for each subject was measured with the Contrast Sensitivity Test Suite program on a computer with maximum luminance and resolution of 1366 × 768 (HP recommended system resolution).
The values for the average of the four sets of Pelli Robson test was entered, alongside the average of the four sets of contrast levels for numbers, blinking and jumping stimuli of the 22 subjects.
All values, figures and tables are represented here, as originally computed using XLSTAT data analysis and statistical solution for Microsoft Excel 2010.
Note: The alphabets N, B, & J attached to the tables and figures represent Numbers, Blinking and Jumping stimulus respectively.

NUMBERS:
This is a search test made up of six screens, each with a number sequence (1-8) as object. The contrast reducing progressively from 1 (0 log unit) to 8 (2.1 log unit), in 0.3log unit steps for the first screen. 1 (.1 log unit) to 8 (2.2 log unit) for the second screen and 1(.2 log unit) to 8 (2.3 log unit) for the third screen. These three screens are repeated twice.

Table N1. Showing the descriptive statistics for the two methods(Pelli Robson and Numbers stimulus of C.S suite).

	Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Pelli	1.75	21	0	21	1.650	1.900	1.748	0.062
CSSN	2.0125	21	0	21	1.538	2.000	1.818	0.127

Table N2. showing the95% confidence interval on the difference between the means

95% confidence interval on the difference between the means:	
0.014	0.127

Table N3: Showing the results of the student t-test performed on the means for each method.

Difference	0.071
t (Observed value)	2.611
t (Critical value)	2.086
DF	20
p-value (Two-tailed)	0.017
Alpha	0.05

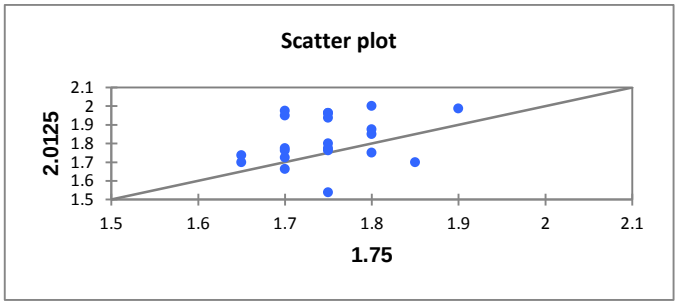

Figure N1Scatter plot showing the distribution of data points between the Pelli Robson chart and the numbers C.S suite

Table N4. Bland-Altman analysis results showing bias, standard error of measurements and 95% confidence interval.

Bland-Altman analysis:		
Bias	0.071	
Standard error	0.124	
CI Bias (95%)	0.014	0.127

Table N5. Confidence interval (Differences)

Confidence interval (Differences):	
-0.173	0.315

Table N6. showing the averages and differences of Pelli and CSSN as plotted on the Bland and Altman plot for each subject.

Average (1.75 + 2.0125)/2	**Difference (2.0125 - 1.75)**
1.763	0.025
1.681	-0.037
1.713	0.025
1.838	0.275
1.694	0.088
1.731	0.063
1.825	0.250
1.644	-0.213
1.775	-0.150
1.775	-0.050
1.675	0.050
1.844	0.188
1.944	0.088
1.738	0.075
1.856	0.213
1.856	0.213
1.900	0.200
1.775	0.050
1.825	0.050
1.756	0.012
1.838	0.075

Table N7. Pearson correlation coefficient with confidence interval showing correlation between the difference and the average.

Pearson correlation coefficient (Average (1.75 + 2.0125)/2 x Difference (2.0125 - 1.75)):	
Correlation CI (95%)	0.632
0.276	0.836

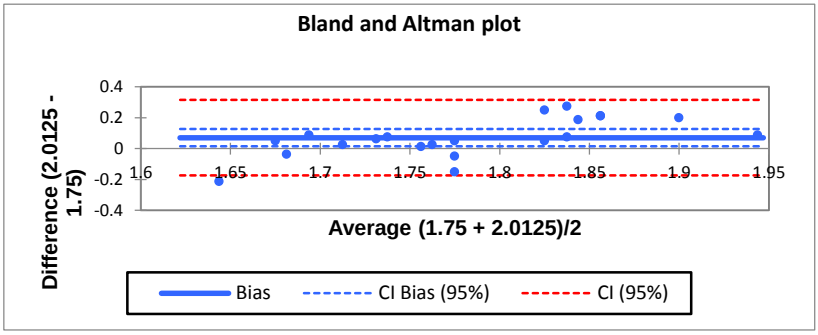

Figure N2. Bland and Altman plot; X axis represents half the average of the four sets of Pelli Robson plus the average of the four sets of contrast levels for numbers stimuli for each of the 22 subjects ((1.75+2.0125)/2)). Y axis represents the difference between the result of the four sets of Pelli Robson test and the average of the four sets of contrast test for numbers stimuli for each of the 22 subjects (1.75-2.0125).

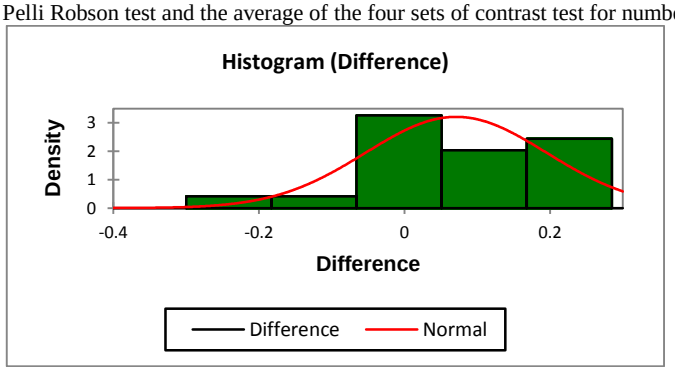

Figure N3. Histogram of the differences

BLINKING:

This is an object detection test. The object is a large blinking square of 30mm, which subtends an angle of 3.5^0 at 50cm. It has 3 trials of 8 screens, with the contrast of the object decreasing in 0.3 log unit steps from 0 log unit to 2.1 log unit sequence in the first trial, 0.1 to 2.2 in the second and 0.2 to 2.3 log unit sequence in the third trial. Exposure time for each screen is 6 secs and a pause of 0.5 secs.

Table B1. Showing the descriptive statistics for the two methods(Pelli Robson and Blinking stimulus of C.S suite.)

	Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Pelli	1.75	21	0	21	1.650	1.900	1.748	0.062
CSSB	2.175	21	0	21	1.613	2.150	1.971	0.150

Table B2. showing the95% confidence interval on the difference between the means

95% confidence interval on the difference between the means:	
0.150	0.298

Table B3. Showing the results of the student t-test performed on the means for each method.

Difference	0.224
t (Observed value)	6.308
t (Critical value)	2.086
DF	20
p-value (Two-tailed)	< 0.0001
Alpha	0.05

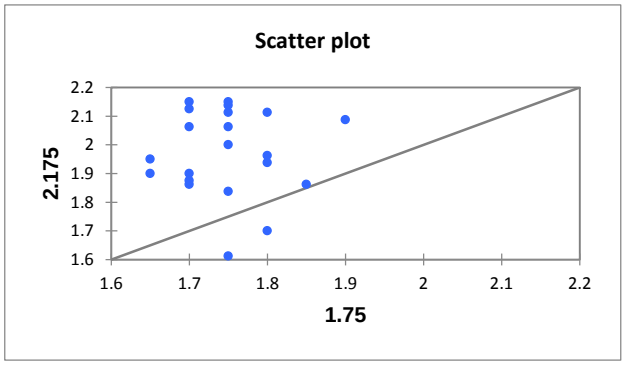

Figure B1.Scatter plot showing the distribution of data points between the Pelli Robson chart and the numbers C.S suite

Table B4. Bland-Altman analysis results showing bias, standard error of measurements and 95% confidence interval

CI Bias (95%)	0.150,	0.298
Bland-Altman analysis:		
Bias	0.224	
Standard error	0.163	

Table B5. Confidence interval (Differences)

Confidence interval (Differences):	
-0.095	**0.542**

Table B6. showing the averages and differences as plotted on the Bland and Altman plot

Average (1.75 + 2.175)/2	**Difference (2.175 - 1.75)**
1.875	0.250
1.800	0.200
1.788	0.175
1.925	0.450
1.800	0.300
1.781	0.163
1.913	0.425
1.681	-0.138
1.856	0.013
1.881	0.163
1.775	0.250
1.944	0.388
1.994	0.188
1.881	0.363
1.931	0.363
1.950	0.400
1.956	0.313
1.906	0.313
1.750	-0.100
1.794	0.087
1.869	0.138

Table B7. Pearson correlation coefficient with confidence interval showing correlation between the difference and the average.

Pearson correlation coefficient (Average (1.75 + 2.175)/2 x Difference (2.175 - 1.75)):		
Correlation CI (95%)	**0.707**	
	0.396	**0.872**

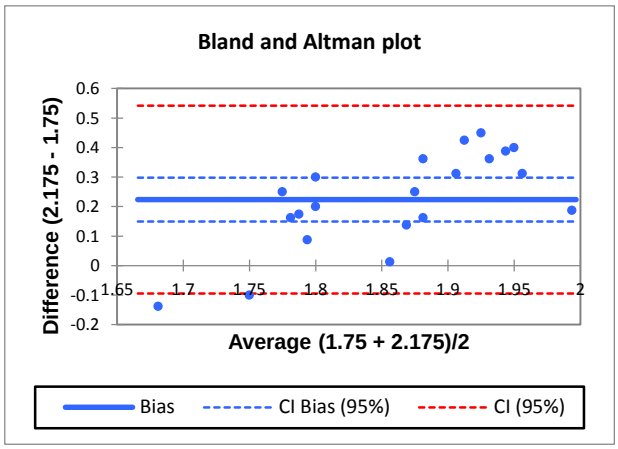

Figure B2. Bland and Altman plot; X axis represents half the average of the four sets of Pelli Robson plus the average of the four sets of contrast levels for numbers stimuli for each of the 22 subjects ((1.75+2.175)/2)). Y axis represents the difference between the result of the four sets of Pelli Robson test and the average of the four sets of contrast test for blinking stimuli for each of the 22 subjects (1.75-2.175).

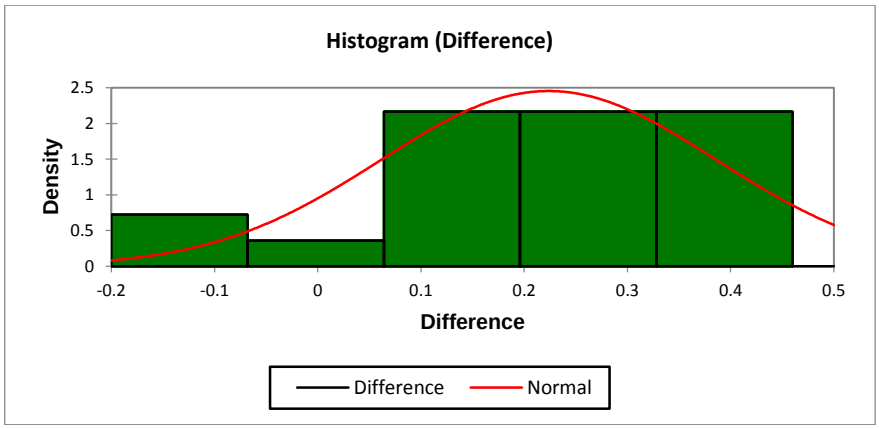

Figure B3. Histogram of the difference???of what

JUMPING:

This is an object detection test. The object is a large jumping square of 30mm, which subtends an angle of 3.5^0 at 50cm. It has 3 trials of 8 screens, with the contrast of the object decreasing in 0.3 log unit steps from 0 log unit to 2.1 log unit sequence in the first trial, 0.1 to 2.2 in the second and 0.2 to 2.3 log unit sequence in the third trial. Exposure time for each screen is 6 secs and a pause of 0.5 secs.

Table J1. Showing the descriptive statistics for the two methods(Pelli Robson and Jumping stimulus of C.S suite.)

	Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Pelli	1.75	21	0	21	1.650	1.900	1.748	0.062
CSSJ	2.2125	21	0	21	1.750	2.175	2.010	0.116

Table J2. showing the95% confidence interval on the difference between the means.

95% confidence interval on the difference between the means:	
0.204	**0.320**

Table J3. Showing the results of the student t-test performed on the means for each method.

Difference	0.262
t (Observed value)	9.364
t (Critical value)	2.086
DF	20
p-value (Two-tailed)	< 0.0001
Alpha	0.05

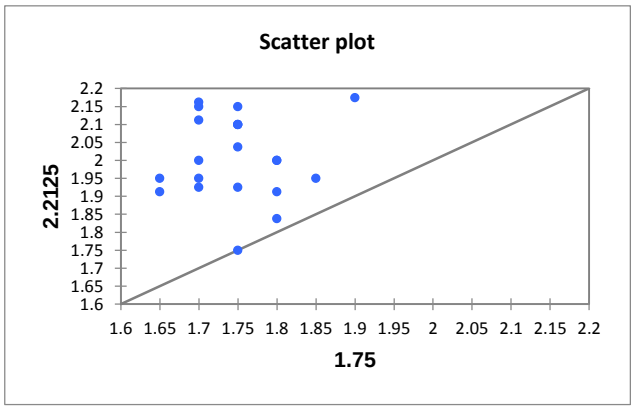

Figure J1.Scatter plot showing the distribution of data points between the Pelli Robson chart and the numbers C.S suite

Table J4. Bland-Altman analysis results showing bias, standard error of measurements and 95% confidence interval.

Bland-Altman analysis:		
Bias	0.262	
Standard error	0.128	
CI Bias (95%)	0.204	0.320

Table J5. Confidence interval (Differences)

Confidence interval (Differences):	
0.011	**0.513**

Table J6. showing the averages and differences as plotted on the Bland and Altman plot

Average (1.75 + 2.2125)/2	Difference (2.2125 - 1.75)
1.925	0.350
1.813	0.225
1.825	0.250
1.906	0.413
1.800	0.300
1.850	0.300
1.931	0.463
1.750	0.000
1.900	0.100
1.900	0.200
1.781	0.263
1.925	0.350
2.038	0.275
1.925	0.450
1.894	0.288
1.925	0.350
1.900	0.200
1.950	0.400
1.819	0.037
1.838	0.175
1.856	0.113

Table J7. Pearson correlation coefficient with confidence interval showing correlation between the difference and the average

Pearson correlation coefficient (Average (1.75 + 2.2125)/2 x Difference (2.2125 - 1.75)):		
Correlation	0.551	
CI (95%)	0.157	0.794

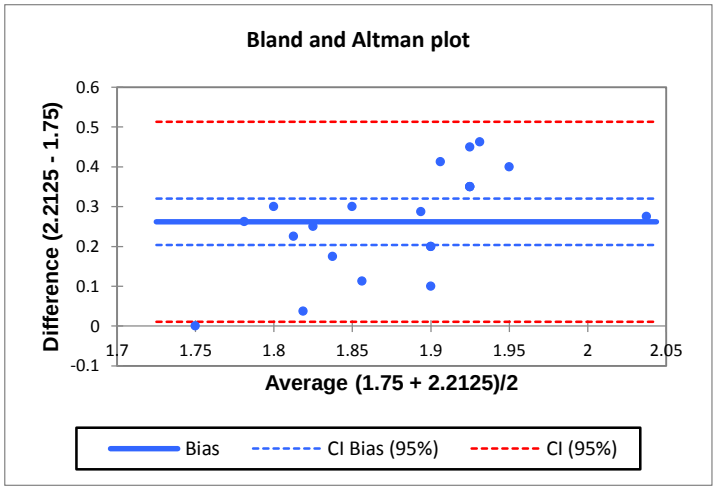

Figure J2. Bland and Altman plot; X axis represents half the average of the four sets of Pelli Robson plus the average of the four sets of contrast levels for numbers stimuli for each of the 22 subjects ((1.75+2.0125)/2)). Y axis represents the difference between the result of the four sets of Pelli Robson test and the average of the four sets of contrast test for numbers stimuli for each of the 22 subjects (1.75-2.0125).

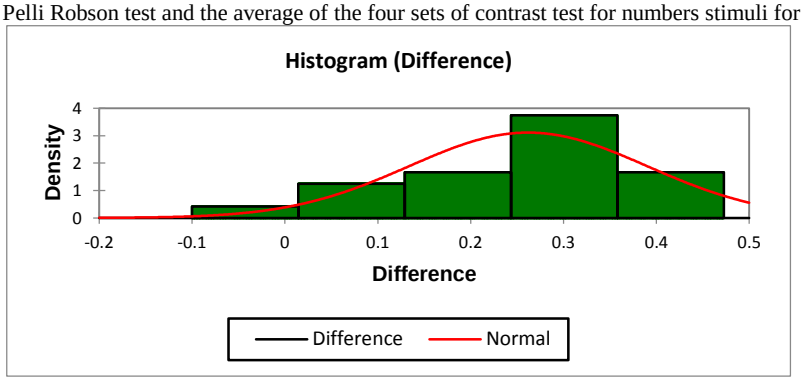

Figure J3. Histogram of the differences

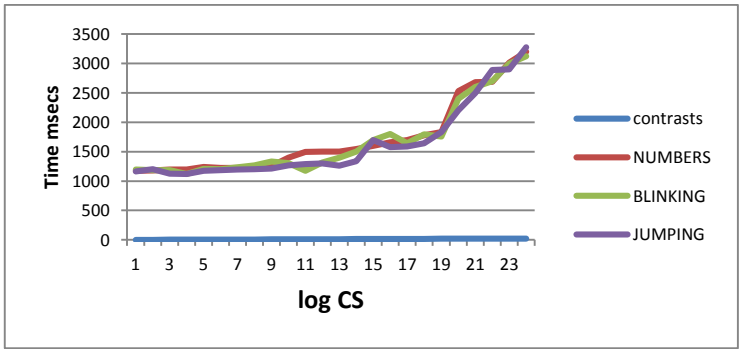

Figure 4: A sample of Graph of reaction time (msecs) versus contrast sensitivity (log CS) for subject 20.

Table N1 revealed that the contrast sensitivity test suite results (C.S test suite) have a larger mean(1.818) compared to Pelli Robson mean value (1.748) and hence, a larger variance than the Pelli Robson results. XLSTAT computes the repeatability as a standard deviation and displays a confidence interval. Ideally, the confidence interval should contain 0. As seen in table N1, B1 and J1 their standard deviations are low but their confidence intervals do not include 0. From tables N3, B3 and J3, we see that the p value is 0.017, <0.0001, <0.001 meaning that the risk of concluding that the methods are different while they would not be is low.

The scatter plots show if there is a fixed bias or not, by comparing the C.S test suites results (ordinates) to the Pelli Robson results (abscissa). The line on the plot is the identity line or bisector. In an ideal case where two methods would give identical results, the data would be on that line. In the numbers, points are above the identical line but points are below and close to the line. This indicates a positive bias, as seen from subsequent analysis. A bias means that by nature, there is a difference between the two methods. Table N3, B3 and J3 reveal very low bias values of 0.017, 0.224 and 0.262 for numbers, blinking and jumping stimuli respectively.

Correlation is a statistical technique that can show whether and how strongly pairs of variables are related. The most common is the Pearson correlation. It is computed as the ratio of covariance between the variables to the product of their standard deviations. The numerical value of r ranges from -1.0 to +1.0. This enables us to get an idea of the strength of the relationship between the variables. Correlation describes linear

relationship between two sets of data but not their agreement. With even a minimal trend, the probability of null hypothesis is very small, and it can be safely, but sometimes erroneously, concluded that the two measurement methods are indeed related [9].
The Bland and Altmanplot system do not say if the agreement is sufficient or suitable to use a method or the other indifferently. It simply quantifies the bias and a range of agreement, within which 95% of the differences between one measurement and the other are included.
The graphs of reaction time vs contrast sensitivity typically show two phases (Figure 4). The first phase is flat and the second phase is an upward swing which starts on the average at about log CS of 1.0 and is more pronounced at log CS 1.2.

DISCUSSION

The main objective of this research was toanalyze the agreement and repeatability between the Pelli Robson chart and the contrast sensitivity test suite. Our findings show that the mean CS in log unit value for the new test were N =1.818, B = 1.971 and J= 2.010 compared to Pelli Robson mean valueof 1.748.Earlier works had put the result with Pelli-Robson as varying from 1.65 in the 60 year and older group to 1.84 in the 20 to 29 and 30 to39 year groups [10,11]. In a study comparing the Pelli-Robson test with another computer test (Test Chart 2000 Xpert), a significant difference was found between the two tests [12], with the computerised test generating higher CS threshold.
The correlation of the Pelli Robson test with the C.S suite has an "r" value of 0.632(numbers), 0.707(blinking) and 0.551(jumping) as shown in tables N7, B7 and J7 respectively. This clearly shows that there is a positive relationship between the Pelli Robson test and the contrast sensitivity test suite. There is no significant difference between the numbers, blinking and jumping stimulus, as represented in table N1, B1 and J1, the low bias values (0.017, 0.224 and 0.262 for numbers, blinking and jumping stimuli respectively in tables N3, B3 and J3) and high correlation values. Therefore, there is a level of agreement and repeatability between the results gotten from the Pelli Robson chart and the contrast sensitivity test suite. The null hypothesis is therefore rejected and the alternate hypotheses(There is a relationship between contrast sensitivity and reaction time results when accessed using the Pelli Robson chart and the contrast sensitivity test suite) is accepted.
We also aimed to determine the stimuli on the contrast sensitivity test suite that most agrees with the Pelli Robson. Data gotten from this study reveals that the blinking stimulus having the highest correlation to the Pelli Robson, with an 'r' value of 0.707. Thus, showing that search task (numbers) took a longer time than detection (blinking) task.
The faster RTs correspond to the relatively flat, high contrast levels in the graphs of reaction time vs. contrast for subject 20 (Figure 4). The discontinuity of this pattern indicates a transition from the parvocellular activity, dominated by the sustained cells, to the magnocellular activity, dominated by the transient cells. An equation that represents the two phases of the graph was given by [13]:

$$RT = RT_0 + k \log CS \quad (1)$$

Where RT is reaction time, RT_0 is the asymptote (absolute) RT, k is the steepness of the curve (representing the contrast gain) and CS is contrast sensitivity. Figure 4 also obeys Piéron's Law, which states that mean response times (MRT) decrease as a power law with increasing stimulus intensity [14]

$$MRT = \alpha I^{-\beta} + \gamma \quad (2)$$

α and β are scaling parameters that determine the slope of the function and γ is an intercept [15].

CONCLUSION

In undertaking this research, findings from results have shown that there is an agreement and repeatability between the results gotten from the Pelli Robson test with those gotten from the contrast sensitivity test suite. It has also shown that the results of the blinking stimulus of the contrast sensitivity test suite had the most agreement with the results gotten from the Pelli Robson contrast sensitivity test.

RECOMMENDATION

The research conducted has revealed that the Pelli Robson test and the contrast sensitivity test suite results are repeatable and as such, can be used interchangeably, when the need arises.

REFERENCES.

[1] O'Carroll, D.C. & Wiederman, S.D. (2014). Contrast sensitivity and the detection of moving patterns and features. *Philosophical transactions, Royal society publications.***369**: (1636):3-25.
[2] Haymes SA, Johnston AW, Heyes AD. Relationship between vision impairment and ability to perform activities of daily living. Ophthsalmic PhysiolOpt 2002; 22: 79-91
[3] West SK, Rubin GS, Broman AT, et al. How does visual impairment affect performance on tasks of everyday life? Arch Ophthalmol 2002; 120: 774-780
[4] Ginsburg AP. Contrast sensitivity: determining the visual quality and function of cataract, intraocular lenses and refractive surgery. Curr Opin Ophthalmol 2006; 17: 19 -26
[5] Barrett, P. (2016). Electrophysiology, chronometrics, and cross-cultural psychometrics at the Biosignal Lab: Why it began, what we learned, and why it ended Personality and Individual Difference. *Journals of Vision.***103**:128–134.
[6] Teichner, W.H. (1954). Recent studies of simple reaction time. *Psychology Bulletin.***51**:128–149.
[7] Bartlett, J.W. & Frost, C. (2008). Reliability, repeatability and reproducibility: analysis of measurement errors in continuous variables. *Ultrasound in obstetrics and Gynaecology.***31**:466-475.
[8] Moinester, M. & Gottfried, R. (2014).Sample size estimation for correlations with pre-specified confidence interval. *The Quantitative Methods for Psychology.***10**(2):124-130.
[9] Giavarina, D. (2015). Understanding Bland Altman Analysis. *Biochemia Medica*.**25(2)**:141-151.
[10] Mantyjarvi M, Laitinen T. Normal values for the Pelli-Robson contrast sensitivity test**.**Journal of Cataract and Refractive Surgery, Volume 27, Issue 2, 2001
[11] Elliot DB, Sanderson K, Conkey A. The reliability of the Pelli-Robson contrast sensitivity chart. Ophthalmic Physiol Opt. 1990 Jan;10(1):21-4.

[12] Arinder C. Do the Pelli – Robson and Test Chart 2000 Xpert demonstrate comparable contrast sensitivity result? Br Ir Orthoptics J 2014; 11:28-33.

[13} Murray IJ, Plainis S. Contrast coding and magno/parvo segregation revealed in reaction times studies. Vision Research 2003;43(25):2707-19.

[14] Van Maanen L, Grasman RPPP, Forstman BU, Wagenmaker E-J. Pieron's law and optimal behavior in perception decision making. *front in Neurosci*2012; 5:143.doi:10.3389/fnins.2011.00143.

[15] Luce RD. Response Times. New York:Oxford University Press; 1986.