Title:

How accurate is an LCD screen version of the Pelli-Robson test?

Running title:

LCD version of the Pelli-Robson test.

Authors

Fabrizio Zeri[*§] PhD, D.Psych, Dip Optom (It), FIACLE, FBCLA**,** FEAOO, **Paolo Calcatelli**[†] Dip Optom (It)**, Eleonora Funaro**[§] D.Opt and Optom**, Marialuisa Martelli**[¶] PhD, D.Psych,**, Shehzad A Naroo**[*] MSc, PhD, , FAAO, FEAOO, FIACLE, FBCLA**, FCOptom**

[*]Ophthalmic Research Group. School of Life and Health Sciences, Aston University, Birmingham, UK

[§]Corso di Laurea in Ottica e Optometria, Università degli Studi di Roma TRE, Italy;

[†] Istituto Ottico Carli di L'Aquila, Italy

[¶]Department of Psychology, Sapienza University of Rome, Italy.

* Corresponding author

Dr. Fabrizio Zeri

Ophthalmic Research Group. School of Life and Health Sciences, Aston University, Birmingham, B4 7ET, UK

E-mail address: f.zeri@aston.ac.uk

Abstract

Purpose: To evaluate the accuracy and repeatability of a computer-generated Pelli-Robson test displayed on liquid crystal display (LCD) systems compared to a standard Pelli-Robson chart.

Method: Two different randomized crossover experiments were carried out for two different LCD systems (MOS and CSO) in a total of 32 people: 6 females and 10 males with mean (40.5 ± 13.0 years) and 9 females and 7 males (27.8 ± 12.2 years) respectively in the first and second experiment.

Two repeated measurements were taken with the Pelli-Robson test and with the LCD system at 1 and 3 m. To test LCD reliability, measurements were repeated after 1 week.

Results: In experiment 1, contrast sensitivity (CS) measured with MOS at 1 m resulted significantly higher than Pelli-Robson of 0.20 and 0.22 log1/C in RE and LE respectively ($p<0.01$). Also at 3 m CS measured with MOS resulted significantly higher than Pelli-Robson of 0.22 log1/C in both eyes ($p<0.01$). Bland–Altman plots showed a proportional bias for MOS measures. MOS measurements showed good repeatability: ICC was 0.83 and 0.65 at 1 and 3 m respectively.

In experiment 2, CS measured with CSO at 1 m resulted significantly lower than Pelli-Robson of 0.13 and 0.12 log1/C in RE and LE respectively. Also at 3 m CS mean measured with CSO resulted significantly lower than Pelli-Robson of 0.10 and 0.07 log1/C in RE and LE respectively. Bland–Altman plots didn't show any proportional bias for CSO measures. CSO measurements showed sufficient repeatability: ICC resulted 0.51 and 0.65 at 1 and 3 m respectively.

Conclusions: Computer-generated versions of Pelli-Robson test, displayed on

LCD systems, don’t provide accurate results compare to classic Pelli-Robson hard version even though their measure repeatability appears to be good. Clinicians should consider that Pelli-Robson computer-generated versions could be non interchangeable to the hard version.

Key words: Contrast sensitivity, LCD Systems, computerised based stimuli, Pelli-Robson test.

Contrast sensitivity (CS) provides noteworthy information about functional vision and allows a better understanding of subtle vision loss potentially due to optical or neurophysiological problems[1] (Elliott, 1998) which can often be less obvious when using static high contrast visual acuity. That is the reason why CS assessment has been using since many years ago in research activity on general disease[2-7] (Howes et al 1982, Kupersmith et al, 1982, Bassi et al, 1993, Russell et al, 1983, Regan et al, 1977, Quiceno et al, 1992), ocular disease[8-12] (Elliott et al, 1989; Arden e Jacobson,1978; Sjöstrand & Frisén, 1977 and 1978; Ibanez et al 1993), refractive surgery[13,14] (Butuner et al, 1994; Wang et al, 1997), contact lenses [15] (e.g. Applegate e Massof, 1975) and orthokeratology [16] (Hiraoka et al, 2007).

However, in clinical practice, CS assessment is much less common for many different reasons, such as a certain difficulty in the procedures, the lacking of a general agreement in a gold standard technique and because a good assessment increases chair time (Martelli & Zeri, 2012, Pelli & Bex, 2013). [17,18]

In order to avoid too much complex and highly time consuming procedures many clinical standard tests do not measure a full CS function. They are usually designed to measure CS at one spatial frequency only, like in a Pelli-Robson chart or in a Small Letter Contrast Test [19,20] (Pelli et al, 1988; Rabin & Wicks, 1996) or to measure visual acuity at lower level of contrast like in Baily Lovie low contrast chart [1] (Elliott, 1998).

In clinical setting, CS assessment has been performed mainly through hard chart, such as Pelli-Robson chart and Baily-Lovie chart while in research CS has been traditionally assessed mainly by computer-generated tests that allow an easier generation of the stimuli features such as font, size and contrast level

and the use of adaptive psychophysics method whereas are impossible to use on test chart [18] (Pelli & Bex, 2013). In research field to assess CS, computer-generated tests were generally connected with cathode ray tube (CRT) monitor that allowed fine control of contrast generation. Through several system such as video attenuators, the 8-bit limit (2^8=256 levels) of Digital to Analog converters (DACs) on the graphics card were increased up to 16-bit of grey-level resolution [21-23] (Pelli & Zhang, 1991; Li et al 2003, Lu & Dosher, 2013).

Nowadays, Liquid Crystal Displays (LCDs) are quickly replacing CRT monitors in workplaces and for other uses because they offer many advantages such as the excellence geometric proprieties, the good pixel independence, the reduction in superficial reflection, the possibility to increase luminance without affecting the size of the pixel and the elimination of flickering [23, 24] (Menozzi et al, 2001; Lu & Dosher, 2014). However LCD displays have disadvantages such as the dependence of viewing angle and the lacking of deep black that limited the contrast ratio [23] (Lu & Dosher, 2014).

In the field of clinical visual assessment, LCD are always more commonly used as optotypes [25] (To et al, 2013), but the possibility to measure CS was limited for long time by the 8-bit luminance resolution of this screens that didn't allow to generate stimuli below the human contrast sensitivity threshold. The contrast ratio of the newer LCD system has improved compare to LCD of previous generation and these systems offer the further advantage of eliminating the loss of quality of the chart due to aging of the test, which could be critical to guarantee the level of contrast printed originally.

Many studies have investigated the reliability of these new devices to assess CS with disparate results [26-29] (Hohberger et al 2007; Thayaparan et al 2007;

Hong et al, 2010, Chandrakumar et al, 2012). Furthermore, LCD technology, is moving CS assessment towards devices such as tablets with interesting clinical perspective [30-32] (Dorr 2013; Kollbaum et al, 2014; Rodríguez-Vallejo et al 2015).

Considering that the most common test to assess contrast sensitivity in research and clinical practice, for its reliability [33-34] (Rubin, 1988, Elliott, 1990), simplicity and speed of procedure [35-40] (Williamson et al 1992; Tan et al, 1998; Haymes et al 2002; Powers, 2009; Kumar et al, 2010; Serbecic et al 2010; Bittner, et al 2014) is the Pelli-Robson chart, many LCD systems, use similar optotypes in clinical practice, include a computerised based Pelli-Robson test (To et al, 2013). [25]

The aim of this study was evaluated accuracy and repeatability of computer-generated Pelli-Robson tests displayed on two LCD systems compare to the standard Pelli-Robson chart.

Method

Subjects and materials

Two cohorts of subjects were recruited, this was to avoid learning effects and to reduce the likelihood of subject fatigue. A randomized crossover experiment was carried out. Two repeated measurements were taken with the Pelli-Robson chart (Clement Clarke International Ltd.; Harlow, U.K.) [19] (Pelli et al, 1988) and with the LCD system. With cohort 1 (Experiment 1) the LCD System was the *MOS: Multi Opti System 24* (DUEFFE TECNOVISION, Pergine Valsugana Italy). In the second cohort (Experiment 2) the LCD System was CSO Vision Chart (Mod CVC02, software CSO Vision Chart v 1.3.0 CSO, Florence, Italy).

,

Inclusion criteria were no ocular pathology, no amblyopia and corrected visual acuity not less than 0.1 logMAR in the worst eye. Habitual prescription was recorded and the habitual visual acuity was measured monocularly. Further objective refraction was carried out with autorefractometer (Essilor; AKE 600, Creteil, France). All subjects had been informed about the experiment in detail and had signed the consent document in compliance with the Declaration of Helsinki before the experiment.

For both LCD systems stimuli were prepared following the Pelli-Robson Chart criteria (Pelli et al, 1988). Two sets (A and B) of sixteen groups of three Sloan letters with the same contrast were set up. The contrast of each single group decreased by a factor of $1/\sqrt{2}$ (0.15 logCS) from a level of 0.00 logCS up to reach a level of 2.25 logCS.

In LCD version the maximum contrast of 0.00 logCS was actually given as 0.03 logCS (equivalent to 93% of contrast) and they could reach a minimum nominal contrast of 2.40 logCS (equivalent to 0.04% of contrast).

In each cohort the Pelli-Robson chart and the LCD screen were placed in a room with constant background luminance. The luminance was measured by a photometer (Chroma meter cs 100 A; Minolta. Tokyo, Japan). Luminance measurements were taken in 4 areas of the white background of each instrument.

In Experiment 1 the mean luminance was 82.6 ± 6 cd/m^2 and 78.7 ± 9 cd/m^2 for the MOS and the Pelli-Robson chart respectively.

In Experiment 2 the mean luminance was 84.0 ± 5 cd/m^2 and 79.4 ± 8 cd/m^2 for the CSO and the Pelli-Robson chart respectively.

According to Pelli et al[19] (1988) the contrast sensitivity threshold was calculated as the level of contrast of the last row that a subject was able to correctly recognize at least 2 out of 3 letters. Each subject was pushed to read all the letters. When subjects read incorrectly the letter “O” instead of “C” or “C” instead of “O” it was not considered a mistake (Elliott Bullimore Bailey 1991). Traditionally two testing distances have been used - the first is at 1 metre, where the angle subtended by the letters is 2.8° and secondly at 3 metres, where the angle decrease up to 0.93°. In order to avoid a potential learning of the letter array and a possible effect of the order of the test presentation, each subject was assigned randomly to one of 8 different sequences (Table 1). Differently from Pelli-Robson chart in which the sixteen triplets are displayed together, in the LCD tests the triplets were presented singularly one after the other due to the limited display screen size.

Each subject was tested for all measurements with their refractive same in place arranged with trial lenses. The same number of trial lenses (two lenses) were used in each case, and if the subject required only one or no trials lenses then plano lenses were added to ensure that any loss of contrast due to the number of lenses was minimised.

To check the LCD measurement reliability the measurements were repeated after 1 week for both cohorts (Table 1).

Data Analysis

The Kolmogorov-Smirnov test was used to evaluate the results for normal distribution of contrast sensitivity data in each condition of the 2 cohorts. All the

distributions (LCD tests and Pelli-Robson at 1 and 3 metres) were statistically different from normality (all $p<0.05$). So, the strength of the relationship between LCD instruments and Pelli-Robson test was evaluated using a non parametric correlation analysis (Spearman correlation coefficient, rho). A Wilcoxon signed rank test was applied to evaluate the differences between the 2 instruments in each cohort. Also, a Bland-Altman plot was used to assess the difference in CS with the 2 instruments for each cohort (Bland & Altman, 1986). [41]
Repeatability was evaluated by performing intraclass correlation coefficient (ICC).

Results

In Experiment 1, subjects were 6 females and 10 males with mean age ± SD of 40.5 ± 13.0 years, range 18-58 years. In Experiment 2, subjects were 9 females and 7 males with mean age ± SD of 27.8 ± 12.2 years, range 15-51 years.

The level of correlation between right eye and left eye was calculated using kappa statistic (Murdoch, 1998). In cohort 1, at 1 metre the right and left eyes were highly correlated both for MOS and Pelli Robson test measurements ($k=0.65$ and $k=0.35$ respectively), but at 3 metres the two eyes were not correlated ($k=0.07$ and $k=0.12$ respectively).
In cohort 2, right and left eyes were not -correlated both for CSO and Pelli Robson test measurements at 1 metre ($k=0.21$ and $k=0.30$ respectively) or at 3 metres ($k=-0.01$ and $k=0.04$ respectively). According to this, analysis performed on both eyes (32 eyes) could be considered reliable for experiment 1 at 3 m and experiment 2 at both distances. In any case all data for both eyes and

separately for right eye left eyes will be reported in the result section for both experiments.

All statistical powers for the accuracy comparisons in both experiments (see Table 2 and 3), performed by Wilcoxon paired test (between LCDs and Pelli-Robson at 1 metre and 3 metres), resulted higher than 0.86 (G Power, 3.1).

Experiment 1

Mean spherical equivalent of the correction in use (11 out of 16 used correction) among the subjects was−0.03 ± 0.81 D (range+1.75/−2.00 D). Monocular habitual visual acuity with correction in use was −0.08 ± 0.06 D (range 0.08/−0.18 D).

In Tab 2 have been reported all the CS measurements and the comparisons. CS mean measured with MOS at 1 meter resulted significantly higher than Pelli-Robson of 0.21, 0.20 and 0.22 log 1/C for all 32 eyes, only right eyes and only left eyes respectively. Also at 3 m CS mean measured with MOS resulted significantly higher than Pelli-Robson of 0.22 either if all 32 eyes, only right eyes or only left eyes were considered.

The correlation between measurements achieved with the 2 instruments resulted significant both at 1 m (Spearman's rho =0.49, $p<0.01$) and at 3 m (Spearman's rho =0.46, $p<0.01$) if 32 eyes were considered.

Bland–Altman plots showed a proportional bias: the difference between measurements with MOS and Pelli-Robson decreased significantly moving to higher contrast sensitivity both at 1 m (Spearman's rho =-0.53 p=0.002) and 3 m (Spearman's rho =-0.46 p=0.008) (Figure 1 and 2). At 1 m the mean difference (MOS minus Pelli-Robson) was 0.21 log 1/C and the limits of agreement (LoA)

were 0.45 and -0.04 log 1/C. At 3 m the mean difference (MOS minus Pelli-Robson) was 0.22 log 1/C and the limits of agreement (LoA) were 0.45 and -0.02 log 1/C. A significant difference between the two measures was found both at 1 and at 3 m (Wilcoxon test; $p < 0.05$) (fixed bias).

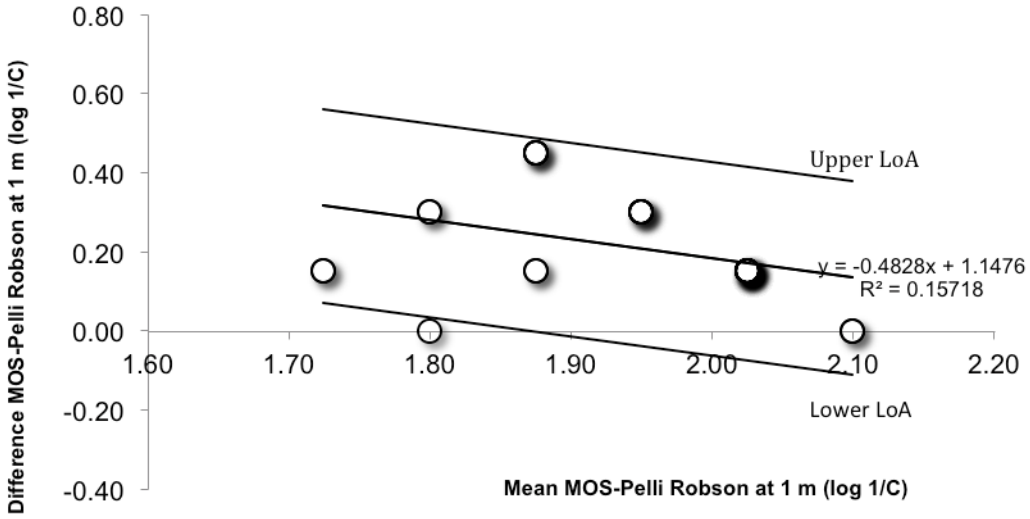

Figure 1. Bland–Altman plot of the differences between MOS and Pelli-Robson in CS measures a 1 m plotted against mean of the two instruments measures (32 eyes). Limits of Agreement are calculated as mean difference ± 1.96 SD of differences, CI at 95% calculated as Bland and Altman [43].

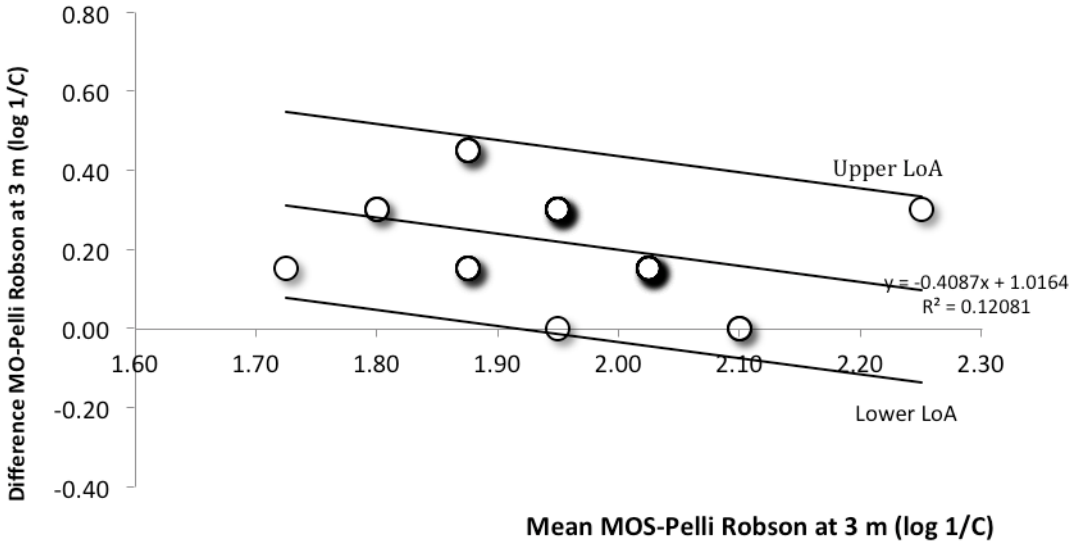

Figure 2. Bland–Altman plot of the differences between MOS and Pelli-Robson in CS measures a 3 m plotted against mean of the two instruments measures (32 eyes). Limits of Agreement are calculated as mean difference ± 1.96 SD of differences, CI at 95% calculated as Bland and Altman [43].

For what concern the repeatability for the MOS, the threshold at retest resulted for the group of 32 eyes 2.08±0.05 log 1/C and 2.13±0.11 log1/C at 1 and 3 meter respectively (Table 2). Spearman's rho resulted 0.77 and 0.49 at 1 and 3 m respectively; both significant $p<0.001$ and $p=0.005$ respectively.

ICC for test–retest reliability calculating for the 32 eyes was 0.83 and 0.65 for 1 m and 3 m respectively. In Table 2 are reported ICCs at both distances, both for the whole group (32 eyes) and for the single eye group

Experiment 2

Mean spherical equivalent of the correction in use (4 out of 16 used correction) among the subjects was−0.13±0.50 D (range+0.25/−2.00 D). Monocular habitual visual acuity was −0.15 ± 0.07 D (range -0.01/−0.28 D).

In Tab 3 have been reported all the CS measurements and the comparisons.

CS mean measured with CSO at 1 meter resulted significantly lower than Pelli-

Robson of 0.13, 0.13 and 0.12 log1/C for all 32 eyes, only right eyes and only left eyes respectively. Also at 3 m CS mean measured with CSO resulted significantly lower than Pelli-Robson of 0.08, 0.10 and 0.07 if all 32 eyes, only right eyes and left eyes were considered.

The correlation between measurements achieved with the 2 instruments resulted significant both at 1 m (Spearman's rho 0.38, $p=0.03$) and at 3 m (Spearman's rho =0.49, $p<0.01$) if 32 eyes were considered.

Bland–Altman plots don't show any proportional bias between the CSO and Pelli-Robson difference and the mean of the two measures: no significant correlation was found either at 1 m (Spearman's rho = -0.218 $p=0.23$) or 3 m (Spearman's rho = 0.02 $p=0.91$) (Figure 3 and 4). At 1 m the mean difference (MOS minus Pelli-Robson) was -0.13 log1/C and the limits of agreement (LoA) were 0.09 and -0.34 log 1/C. At 3 m the mean difference (MOS minus Pelli Robson) was 0.21 log1/C and the limits of agreement (LoA) were 0.15 and -0.32 log1/C. A significant difference between the two measures was found both at 1 and at 3 m (Wilcoxon test; $p < 0.05$) (fixed bias).

In terms of repeatability the CSO measurements showed quite good reliability at both distance when both eyes were considered: ICC 0.51 and 0.65 at 1 and 3 m respectively.

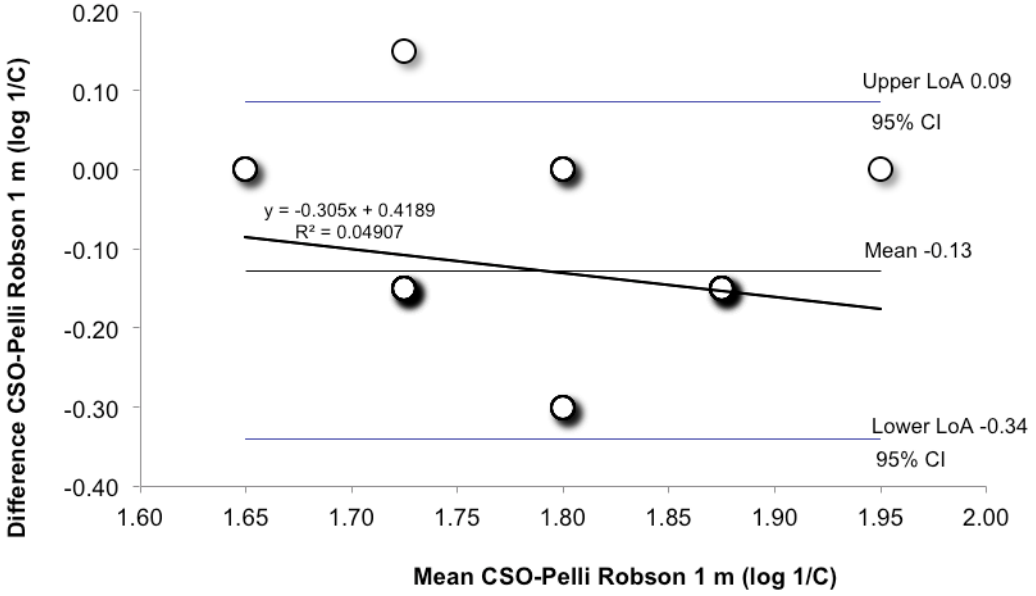

Figure 3. Bland–Altman plot of the differences between CSO and Pelli-Robson in CS measures a 1 m plotted against mean of the two instruments measures (32 eyes). Limits of Agreement are calculated as mean difference ± 1.96 SD of differences, CI at 95% calculated as Bland and Altman [43].

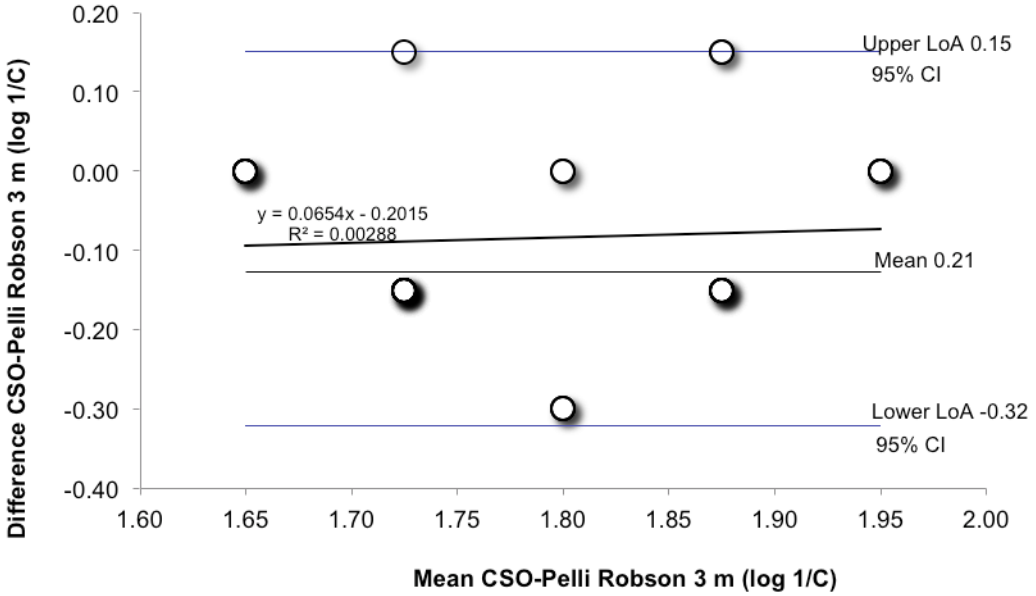

Figure 4. Bland–Altman plot of the differences between CSO and Pelli-Robson in CS measures a 3 m plotted against mean of the two instruments measures (32 eyes). Limits of Agreement are calculated as mean difference ± 1.96 SD of differences, CI at 95% calculated as Bland and Altman [43].

Discussion

The aim of this study was to evaluate the accuracy and repeatability of computer-generated Pelli-Robson tests displayed on two LCD systems compared to a standard Pelli-Robson chart, which is considered highly reliable [33,34] (Rubin, 1988, Elliott, 1990).

First of all, the two computerized systems have shown a good repeatability measured at both distances. This ensures that clinical testing of the same patient would be stable in time.

Pelli-Robson contrast sensitivity results obtained with the standard chart test were very similar, at both viewing distances, to normative data for healthy subjects in the same age-range [44] (Mantyjarvi and Laitinen, 2001). However, significant differences with the normative data were found when comparing the two computerized version of the test. The difference is in the opposite direction: the MOS produced an average 12% overestimation of the CS, while the CSO underestimated the CS of about 6%. These differences appear to be relevant in a clinical perspective; they are close to a step of contrast (0.15 log1/C) measured with the standard Pelli-Robson chart or even higher as in the case of MOS. The two instruments have also shown a different reliability as a function of the CS value measured with the Bland Altman test. In this case, only the MOS shows a proportional bias.

Similarly, Thayaparan and coll.[27] (2007) have reported a poor agreement between the standard Pelli-Robson chart and a version of the test displayed on an LCD (TestChart 2000). They found an overestimation of the CS and an extremely poor level of agreement measured with the Bland Altman plot (1.00

log unit, i.e. about double the size reported here of 0.48 for the MOS and 0.40 for the CSO, Figure 1 to 4)

It is not simple to try to explain the lack of accuracy of the 2 instruments compared to Pelli-Robson chart given their good repeatability.

The slight difference of luminance between LCDs and Pelli-Robson chart that was measured, about 4 and 5 cd/m^2 in experiment 1 and 2 respectively, cannot justify the differences in CS found [45] (De Valois et al, 1974).

Thayaparan and collegues [27] (2007), attributed the poor accuracy of the LCD system to the sub-optimal performance in generating low-level contrasts. This was suggested by the fact that the level of agreement (Bland Altman) dramatically improved when only subjects with a contrast sensitivity ≤1.70 log1/C were included in the analysis.

Crucial for the CS estimation, especially at low contrasts, is an adequate luminance calibration of the LCD [25] (To et al, 2013). However, in a clinical setting performing a sophisticated luminance measure to calibrate the LCDs goes far beyond the skills and the equipment available, which should be the manufacturer's commitment. Nonetheless, results of this study provide some relevant insights on how and when to use such instruments. Clinicians should be aware to consistently compare patients with the same instrument and not across tests. Indeed, both the LCDs tested here are not interchangeable with the standard Pelli-Robson chart. However, both systems have shown good repeatability and a clear improvement in accuracy relative to previous systems (Thayaparan, 2007). Additionally, the LCD tests should not be used when a subtle measure at the lowest levels of contrasts is required, such as in comparing the quality of two optical corrections.

Future devolvement in LCD technology is still needed to improve reliability of the CS assessment in order to ensure its wider diffusion in clinical practice.

Acknowledgements
We wish to thank Dueffe Tecno Vision (Pergine Valsugana, Italy) and CSO (Florence, Italy) for providing MOS and Vision Chart used in Experiment 1 and Experiment 2 respectively.

Conflicts of Interest Disclosure
The authors report no conflicts of interest and have no proprietary interest in any of the materials mentioned in this article.

Funding Sources Disclosure
This research received no funding from any source. Dr. Fabrizio Zeri is funded with the support of the European Union under a Marie Curie Intra-European Fellowship for Career Development.

References

1. Elliott DB. Contrat sensitivity ad glare testing. In: Benjamin WJ ed. Borish's Clinical Refraction, 2nd ed. Philadelphia: WB Saunders Company, 1998. p 247-288.
2. Howes SC, Caelli T, Mitchell P. Contrast sensitivity in diabetics with retinopathy and cataract. Aust J Ophthalmol 1982; 10: 173-178.
3. Kupersmith MJ, Shakin E, Siegel IM, Lieberman A. Visual system abnormalities in patients with Parkinson’s disease. Arch Neurol 1982; 39: 284-286.
4. Bassi CJ, Solomon K, Young D. Vision in aging and dementia. Optom Vis Sci 1993; 70: 809-813.
5. Russell P, Sekuler R, Roxe D, Messersmith R, Mulvanny P. (1983) Contrast sensitivity of hemodialysispatients. Metab Pediatr Syst Ophthalmol, 7, 201-206.
6. Regan D, Silver R, Murray TJ. Visual acuity and contrast sensitivity in multiple sclerosis-- hidden visual loss: an auxiliary diagnostic test. Brain 1977; 100: 563-579.
7. Quiceno JI, Capparelli E, Sadun AA, Munguia D, Grant I, Listhaus A, Crapotta J, Lambert B, Freeman WR. Visual dysfunction without retinitis in patients with acquired immunodeficiencysyndrome. Am J Ophthalmol 1992;

113: 8-13.

8. Elliott DB, Gilchrist J, Whitaker D. Contrast sensitivity and glare sensitivity changes with three types of cataract morphology: are these techniques necessary in a clinical evaluation of cataract? Ophthalmic Physiol Opt 1989; 9: 25-30.
9. Arden GB, Jacobson JJ. A simple grating test for contrast sensitivity: preliminary results indicate value in screening for glaucoma. Invest Ophthalmol Vis Sci 1978; 17: 23-32.
10. Sjöstrand J, Frisén L. Contrast sensitivity in macular disease. A preliminary report. Acta Ophthalmol (Copenh) 1977; 55: 507-514.
11. Sjöstrand J, Frisén L. Contrast sensitivity in optics neuritis: A preliminary report. Doc Ophthalmol Proc Ser 1978; 17: 165-74.
12. Ibanez HE, Lesher MP, Singerman LJ, Rice TA, Keep GF. Prospective evaluation of the effect of pseudophakic cystoid macula edema on contrast sensitivity. Arch Ophthalmol 1993; 111: 1635-1639.
13. Butuner Z, Elliott DB, Gimbel HV, Slimmon S. Visual function one year after excimer laser photorefractive keratectomy. J Refract Corneal Surg 1994; 10: 625-30.
14. Wang Z, Chen J, Yang B. Comparison of laser in situ keratomileusis and photorefractive keratectomy to correct myopia from -1.25 to -6.00 diopters. J Refract Surg 1997; 13: 528-34.
15. Applegate RA, Massof RW. Changes in the contrast sensitivity function induced by contact lens wear. Am J Optom Physiol Opt 1975; 52: 840-6.
16. Hiraoka T, Okamoto C, Ishii Y, Kakita T, Oshika T. Contrast sensitivity function and ocular higher-order aberrations following overnight orthokeratology. Invest Ophthalmol Vis Sci 2007; 48: 550-6.
17. Martelli M, Zeri F. Dall'immagine retinica all'elaborazione dell'informazione visiva In: Zeri F, Rossetti A, Fossetti A, Calossi A. eds. Ottica Visuale. Roma; SEU, 2012. p.315-361.
18. Pelli DG, Bex P. Measuring contrast sensitivity. Vision Res 2013; 90:10-14.
19. Pelli DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. Clin Vis Sci 1988; 2: 187-199.
20. Rabin J, Wicks J. Measuring resolution in the contrast domain: the small letter contrast test. Optom Vis Sci 1996; 73: 398-403.
21. Pelli DG, Zhang L. Accurate control of contrast on microcomputer displays. Vision Research. 1991; 31: 1337-1350.
22. Li X, Lu ZL, Xu P, Jin J, Zhou Y. Generating high gray-level resolution monochrome displays with conventional computer graphics cards and color monitors. Journal of Neuroscience Methods 2003; 130: 9-18.
23. Lu ZL, Dosher B. Visual psychophysics: From laboratory to theory. MIT Press, 2013.
24. Menozzi M, Lang F, Naepflin U, Zeller C, Krueger H. CRT versus LCD:

Effects of refresh rate, display technology and background luminance in visual performance. Displays 2001; 22; 79-85.

25. To L, Woods RL, Goldstein RB, Peli E. Psychophysical contrast calibration. Vision research 2013; 90: 15-24.

26. Hohberger B, Laemmer R, Adler W, Juenemann AG, Horn FK. Measuring contrast sensitivity in normal subjects with OPTEC 6500: influence of age and glare. Graefes Arch Clin Exp Ophthalmol 2007; 245: 1805-1814.

27. Thayaparan K, Crossland MD, Rubin GS. Clinical assessment of two new contrast sensitivity charts. Br J Ophthalmol 2007; 91: 749-52.

28. Hong YT, Kim SW, Kim EK, Kim TI. Contrast sensitivity measurement with 2 contrast sensitivity tests in normal eyes and eyes with cataract. J Cataract Refract Surg 2010; 36: 547-552.

29. Chandrakumar M, Reginald YA, Colpa L, Cotesta M, Panton C, Westall CA, Wong AM. A new method for testing letter Contrast Sensitivity in a clinical setting: comparing M&S Smart System II Letter Contrast Test With Pelli-robson Chart. Inv Ophthalm Vis Sci 2012; 53: 5463-5463.

30. Dorr M, Lesmes LA, Lu ZL, Bex PJ. Rapid and reliable assess-ment of the contrast sensitivity function on an iPad. Inv Ophthal Vis Sci 2013; 54:7266-7273.

31. Kollbaum PS, Jansen ME, Kollbaum EJ, Bullimore MA. Validationof an iPad test of letter contrast sensitivity. Optom Vis Sci 2014; 91: 291-296.

32. Rodríguez-Vallejo M, Remón L, Monsoriu JA, Furlan WD. Designing a new test for contrast sensitivity function measurement with iPad. Journal of Optometry 2015; 8: 101-108.

33. Rubin GS. Reliability and sensitivity of clinical contrast sensitivity tests. Clin Vision Sci 1988; 2: 169–177.

34. Elliott DB, Sanderson K, Conkey, A. The reliability of the Pelli-Robson contrast sensitivity chart. Ophthalmic and Physiological Optics 1990; 10: 21-24.

35. Williamson TH, Strong NP, Sparrow J, et al. Contrast sensitivity and glare in cataract using the Pelli-Robson chart. Br J Ophthalmol 1992; 76:719–722

36. Tan JCH, Spalton DJ, Arden GB. Comparison of methods to assess visual impairment from glare and light scattering with posterior capsule opacification. J Cataract Refract Surg 1998; 24:1626–1631.

37. Haymes, SA, Johnston, AW, Heyes AD. Relationship between vision impairment and ability to perform activities of daily living. Ophthalmic and Physiological Optics 2002; 22; 79-91.

38. Powers MK. Paper tools for assessing visual function. Optometry & Vision Science 2009; 86: 613-618.

39. Kumar V, Ghosh B, Mehta DK, Goel N. Functional outcome of subthreshold versus threshold diode laser photocoagulation in diabetic macular oedema. Eye 2010; 24: 1459-1465.

40. Serbecic, N., Aboul-Enein, F., Beutelspacher, S. C., Graf, M., Kircher, K.,

Geitzenauer, W., ... & Reitner, A. Heterogeneous pattern of retinal nerve fiber layer in multiple sclerosis. High resolution optical coherence tomography: potential and limitations. PLoS One 2010; 5: e13877.

41. Bland JM, Altman DG. Statistical methods for assessing agreement between twomethods of clinical measurement. Lancet 1986; 1: 307-310.

42. Murdoch IE, Morris SS, Cousens SN. People and eyes: sta-tistical approaches in ophthalmology. Br J Ophthalmol1998; 82: 971-973.

43. Bland JM, Altman DG. Statistical methods for assessing agreement between twomethods of clinical measurement. Int J Nurs Stud 2010; 47: 931–6.

44. Mäntyjärvi, M., & Laitinen, T. Normal values for the Pelli-Robson contrast sensitivity test. Journal of Cataract & Refractive Surgery 2001; 27: 261-266.

45. De Valois RL, Morgan H, Snodderly DM. Psychophysical studies of monkey vision. 3. Spatial luminance contrast sensitivity tests of macaque and human observers. Vision Res 1974; 14: 75-81.

Order of measurements

	1 meter				3 meters				Retest 1 meter		Retest 3 meters	
Condition	**RE**		**LE**		**RE**		**LE**		**LE**	**RE**	**LE**	**RE**
I	Pelli-Robson A	LCD A	Pelli-Robson B	LCD B	Pelli-Robson A	LCD A	Pelli-Robson B	LCD B	LCD A	LCD B	LCD A	LCD B
II	Pelli-Robson A	LCD A	LCD B	Pelli-Robson B	Pelli-Robson A	LCD A	LCD B	Pelli-Robson B	LCD A	LCD B	LCD A	LCD B
III	LCD A	Pelli-Robson A	Pelli-Robson B	LCD B	LCD A	Pelli-Robson A	Pelli-Robson B	LCD B	LCD A	LCD B	LCD A	LCD B
IV	LCD A	Pelli-Robson A	LCD B	Pelli-Robson B	LCD A	Pelli-Robson A	LCD B	Pelli-Robson B	LCD A	LCD B	LCD A	LCD B
V	Pelli-Robson B	LDC B	Pelli-Robson A	LCD A	Pelli-Robson B	LCD B	Pelli-Robson A	LCD A	LCD B	LCD A	LCD B	LCD A
VI	LCD B	Pelli-Robson B	Pelli-Robson A	LCD A	LCD B	Pelli-Robson B	Pelli-Robson A	LCD A	LCD B	LCD A	LCD B	LCD A
VII	Pelli-Robson B	LCD B	LCD A	Pelli-Robson A	Pelli-Robson B	LCD B	LCD A	Pelli-Robson A	LCD B	LCD A	LCD B	LCD A
VIII	LCD B	Pelli-Robson B	LCD A	Pelli-Robson A	LCD B	Pelli-Robson B	LCD A	Pelli-Robson A	LCD B	LCD A	LCD B	LCD A

Table 1: Sketch of the procedure followed during the two different experiments. There has been reported the order of measurements taken during the first session (accuracy) and retest (LCD repeatability) for the 8 condition of which each single subject was assigned to. Pelli-Robson A: side A. Pelli-Robson B: side B. LCD A: MOS (Exp1) or CSO (Exp2) set of letter arranged in the same way of Pelli-Robson chart side A. LCD B: MOS (Experiment 1) or CSO (Experiment 2) set of letter arranged in the same way of Pelli-Robson chart side B.

		MOS 1 m (log1/C)	MOS 3 m (log1/C)	Pelli-Robson 1 m (log1/C)	Pelli-Robson 3 m (log1/C)	MOS Retest 1 m (log1/C)	MOS Retest 3 m (log1/C)	Comparison MOS Pelli-Robson at 1 m	Comparison MOS Pelli-Robson at 3 m	Comparison MOS test retest 1 m	Comparison MOS test retest 3 m
All 32 eyes	Median	2.10	2.10	1.88	1.80	2.10	2.10	Wilcoxon p<0.01	Wilcoxon p<0.01	ICC=0.83	ICC=0.65
	Mean	2.05	2.07	1.85	1.85	2.08	2.13	Spearman's rho=0.52 p<0.01	Spearman's rho=0.46 p<0.01	Spearman's rho=0.77 p<0.001	Spearman's rho=0.49 p<0.01
	SD	0.10	0.10	0.14	0.14	0.05	0.11				
RE 16 eyes	Median	2.10	2.10	1.95	1.88	2.10	2.10	Wilcoxon p<0.01	Wilcoxon p<0.01	ICC=0.85	ICC=0.17
	Mean	2.06	2.08	1.87	1.87	2.08	2.12	Spearman's rho=0.61 p=0.01	Spearman's rho=0.44 p=0.09	Spearman's rho=0.81 p<0.001	Spearman's rho =0.10 p=0.72
	SD	0.09	0.05	0.13	0.12	0.05	0.08				
LE 16 eyes	Median	2.10	2.10	1.80	1.80	2.10	2.10	Wilcoxon p<0.01	Wilcoxon p<0.01	ICC=0.81	ICC=0.75
	Mean	2.04	2.05	1.83	1.84	2.08	2.14	Spearman's rho=0.42 p=0.10	Spearman's rho=0.45 p=0.08	Spearman's rho=0.76 p<0.01	Spearman's rho =0.59 p=0.02
	SD	0.11	0.13	0.15	0.15	0.05	0.14				

Table 2: Descriptive statistics of the contrast sensitivity (log 1/C) measured in Experiment 1. Accuracy comparisons. Repeatability outcomes.

		CSO 1 m (log1/C)	CSO 3 m (log1/C)	Pelli-Robson 1 m (log1/C)	Pelli-Robson 3 m (log1/C)	CSO Retest 1 m (log1/C)	CSORetest 3 m (log1/C)	Comparison CSO Pelli-Robson at 1 m	Comparison CSO Pelli-Robson at 3 m	Comparison CSO test retest 1 m	Comparison CSO test retest 3 m
All 32 eyes	Median	1.65	1.65	1.80	1.80	1.80	1.80	Wilcoxon p<0.01	Wilcoxon p<0.01	ICC=0.51	ICC=0.65
	Mean	1.73	1.75	1.85	1.83	1.78	1.82	Spearman's rho =0.38 p=0.03	Spearman's rho =0.49 p<0.01	Spearman's rho =0.36 p=0.04	Spearman's rho =0.51 p<0.01
	SD	0.09	0.12	0.11	0.11	0.10	0.11				
RE 16 eyes	Median	1.65	1.65	1.95	1.80	1.80	1.80	Wilcoxon p<0.01	Wilcoxon p=0.02	ICC=0.15	ICC=0.54
	Mean	1.73	1.73	1.86	1.84	1.77	1.77	Spearman's rho =0.27 p=0.31	Spearman's rho =0.23 p=0.39	Spearman's rho =0.08 p=0.78	Spearman's rho =0.47 p=0.07
	SD	0.09	0.12	0.12	0.10	0.10	0.08				
LE 16 eyes	Median	1.73	1.80	1.80	1.80	1.80	1.95	Wilcoxon p<0.01	Wilcoxon p=0.02	ICC=0.78	ICC=0.72
	Mean	1.73	1.76	1.85	1.83	1.79	1.87	Spearman's rho =0.54 p=0.03	Spearman's rho =0.74 p<0.01	Spearman's rho =0.67 p<0.01	Spearman's rho =0.57 p=0.02
	SD	0.08	0.12	0.09	0.13	0.10	0.11				

Table 3: Descriptive statistics of the contrast sensitivity (log 1/C) measured in Experiment 2 Accuracy comparisons. Repeatability outcomes.