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Visual function measurement using a laptop computer: does the screen angle matter?

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Abstract

Aim: **Computerised vision assessment on a laptop provides increased portability and flexibility. However, when a laptop screen is tilted it can alter the visibility of information on the screen. This study evaluated the effect of changing the laptop screen angle on visual acuity (VA) and contrast sensitivity (CS) measurements and compared the results with those obtained using standard clinical tests.**

Methods: **VA and CS were measured with the screen at five angles (80°–100°) in 5° intervals in a randomised order. The ETDRS chart and Pelli–Robson chart were used as standard clinical tests.**

Results: **VA laptop scores were not affected by tilting the screen and were comparable with the ETDRS scores. CS measurements were directly proportional to the screen angle with a mean increase of 0.11 logCS units for every 5° increase. The laptop CS measurement was closest to the Pelli–Robson result at an angle of 100°; but the laptop measurement was still on average 0.44 logCS units lower and analysis showed considerable variability between the two tests.**

Conclusions: **The variability between the CS tests means that they are not interchangeable. VA measurements were not affected by the screen angle and produced measurements within normal limits compared with the standard clinical test.**

Key words: Contrast sensitivity, Laptop, Visual acuity

Introduction

Over recent years there have been significant changes in the way in which visual acuity is assessed, which began with the introduction of the logMAR charts.[1] In addition there have been variations in the way the optotypes are presented, including the development of computerised systems. These computerised systems enable a flexible approach to assessment, allowing the selection of optotypes at varying contrasts with or without crowding bars over a large range of test distances, whilst maintaining a standardised approach. There have been several reports on the use of these systems in which they have been evaluated and successfully implemented in a number of areas of ophthalmic research.[2–4]

As, in addition to laboratory- or hospital-based testing, assessments may take place in a variety of settings, a portable option for vision assessment is desirable. Gouthaman *et al.*[5] developed a customised portable logMAR chart which demonstrated a good level of agreement with the standard ETDRS chart.[6] However, unlike the computerised systems, this chart could not provide different test types, crowded bars or varying contrast. An alternative is to install testing software onto a laptop computer, which combines portability with flexible test options. This approach has been used in a number of settings including a rural setting in East Africa.[7]

While it is possible to maintain standardisation between a standard CRT monitor and a laptop screen for many factors, such as calibrating the screen to ensure equal letter sizes, there are other important respects in which there are differences. In particular the position of a laptop screen is variable, and with this variation comes a variation in the apparent visibility of information presented on the screen. This is particularly marked when the screen is tilted. This has a potentially significant impact on any measurements made, particularly for contrast sensitivity. However, the magnitude of this impact and whether it is significant is unknown. We therefore conducted a number of experiments to determine the effect of tilting a laptop screen on visual acuity (VA) and contrast sensitivity (CS). In addition, by comparing the results with measurements on standard test charts (ETDRS VA chart and Pelli–Robson CS chart), the relationships between the tests were investigated.

Methods

The Test Chart 2000 Pro software (Thompson Software Solutions) was loaded onto a Dell Latitude 505 laptop and controlled with a remote control via an infrared receiver plugged into a USB port. No guidelines regarding optimum screen angle were found in either the users' manual for this laptop or the test software.

Subjects with no known ocular disorders and of a wide variety of ages were recruited. All subjects gave informed consent and the study complied with the tenets

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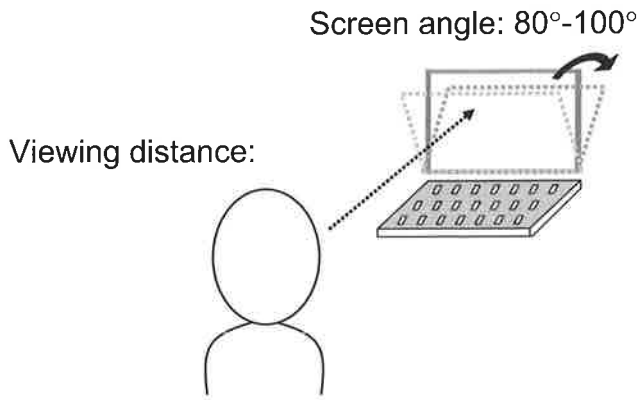

Fig. 1. Diagrammatic representation of the set-up for testing the effect of the angle of the laptop screen. The subject's position and distance from the laptop was fixed; the base of the laptop did not move. The screen was pivoted about the hinge in the normal way. Angle was varied between 80° and 100°, where 90° meant the screen was vertical.

of the Declaration of Helsinki. For both VA and CS measurements the subjects were tested monocularly; the subject selected their better seeing eye. To maintain a constant level of ambient light, the windows in the testing room were covered, and the overhead lighting was switched on at all times.

The viewing distance (1 m for CS and 6 m for VA) and direction of the laptop were fixed relative to the subject as shown in Fig. 1.

The angle of the laptop screen was altered and measured using a protractor. The accuracy of the setting of the angle of the screen (i.e. the degree of screen tilt) was assessed. With the addition of a marker to the laptop, this was $\pm 0.5°$.

The VA and CS were measured with the screen at five angles: 80° (screen tilted towards the subject), 85°, 90°, 95° and 100° (screen tilted away from the subject). Angles beyond this range limited the visibility of the whole screen and obscured some of the letters at the top or bottom of the screen. In addition, very large angles produced a negative image, enhancing the visibility of the CS letters. The order in which the tests were carried out was recorded and changed from subject to subject to minimise the impact of any practice effect or fatigue.

Visual acuity

A standardised logMAR chart was used to assess VA at 6 m. Acuities were scored per letter with the subject starting at the 0.5 line and ending when three or more letters on a line were incorrect. The same threshold estimation method was used for both tests. Although the head position was not fixed the subject was positioned with their eye level central to the chart.

On the computerised version, the letters were presented as a single line to ensure the visual angle remained constant throughout testing. It is recognised that this reduces the crowding effect found on the chart[8] and could therefore potentially give a higher reading using a single line on the computer test. However, no subjects in this cohort had amblyopia. In addition the crowding effect has been reported as absent in optotypes arranged vertically;[9] therefore it was anticipated that any impact would be minimal.

Contrast sensitivity

CS was measured using the Pelli–Robson contrast sensitivity chart and the equivalent test on the laptop, which uses the same test distance, letters and scoring. The test distance was 1 m and, as recommended by Elliott *et al.*,[10] it was scored per letter (each letter = 0.05 logCS units) and the letters C and O were used interchangeably; this has been shown to improve test reliability.[10] Subjects were positioned with their chin on a rest, the height of which was adjusted to ensure that the eyes were level with the centre of the computer screen. Cheek pads further minimised any head movement.

On the laptop test, three lines were presented on each screen. Subjects were instructed to read the centre line only, again to ensure that the viewing angle remained constant. In addition the letters presented were randomised so that all three lines changed every time the CS was increased.

Statistical methods

All the data were entered into, and analysed with, SPSS version 11. A linear regression analysis was performed to determine whether there was any relationship between the screen angle and the measurement of both VA and CS. The level of agreement between tests was assessed using Bland–Altman analysis.[11,12] Bland–Altman analysis is used to investigate the level of agreement between two measurements. The average difference between the two tests is called the bias.

Results

A total of 60 subjects were assessed: 19 males and 41 females. Mean age was 36.8 years (median 39 years, range 7–61 years).

The measured VA at each angle was compared; while there was some variation in VA measurements across the range of screen angles, there was no pattern to this variation (Fig. 2). The mean VA varied from a minimum of 0.011 at 90° to a maximum of 0.048 at 100°. Linear regression analysis provided no evidence of any linear relationship between screen angle and VA ($p = 0.5$, $r^2 = 0.17$).

However, when assessing the impact of screen tilt on CS measurements, we found that the angle of tilt significantly affected the measured CS. As shown in Fig. 3, when the screen angle increased over the range used in these experiments (80° to 100°) the CS varied systematically. Indeed there was a directly proportional increase in measured CS with an increase in angle; this relationship was statistically significant ($p < 0.001$, $r^2 = 0.81$).

To address the second aim of determining the level of agreement between the laptop and standardised testing, the results at each angle were compared with the Pelli–Robson chart measurements. Table 1 (see also Fig. 3) shows that the measurement at 100° is the closest to the

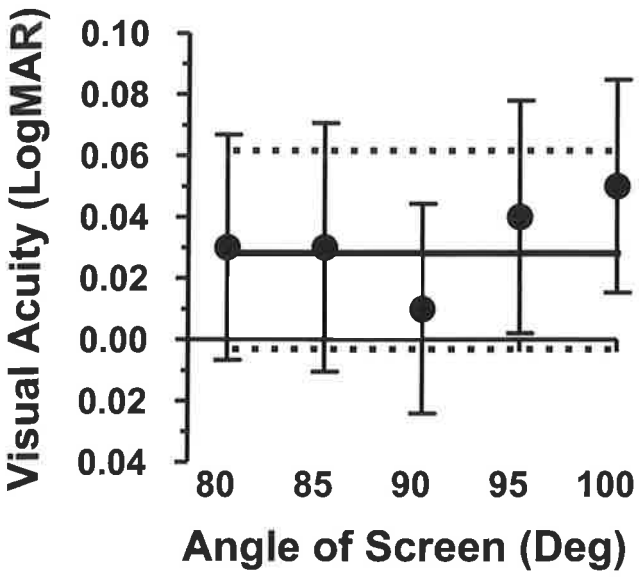

Fig. 2. Mean (±95% CI) static visual acuity (logMAR) measured with the laptop screen at different angles. The unbroken line is mean logMAR chart acuity; dashed lines are ±95% CI.

Pelli–Robson measurement; however, the laptop measurement is still considerably lower than the Pelli–Robson measurement (difference in the mean values = 0.44 logCS units).

As there was little variation in acuity across the angles, the measurements at 100° were used for consistency with the CS measurements, this being the angle which gave the closest values to the Pelli–Robson

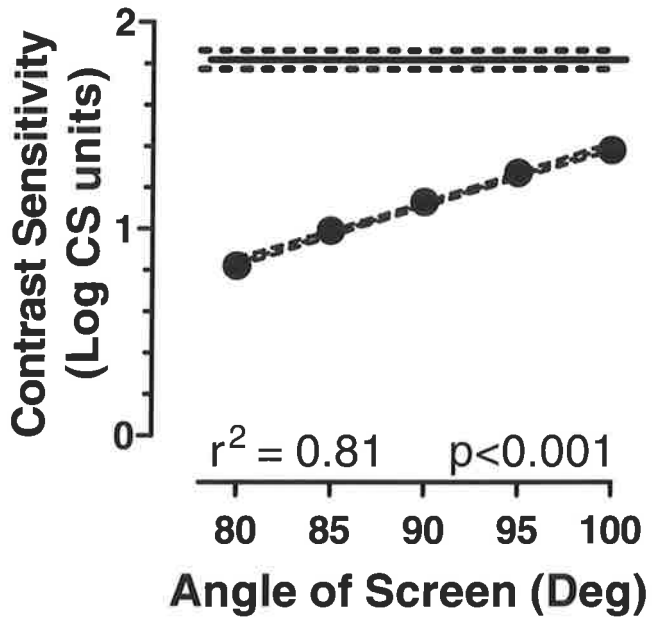

Fig. 3. Mean (±95% CI; error bars smaller than symbols) contrast sensitivity (logCS units) with the laptop screen at different angles. The dashed line is the least-squares linear regression calculated from the dataset (slope 0.028, intercept −1.41, r^2 0.81). The unbroken line is mean CS (±95% CI) measured using the Pelli–Robson chart.

Table 1. The laptop contrast sensitivity measurements (logCS units) at five screen angles and the Pelli–Robson chart results

	Angle (deg)					
	80	85	90	95	100	Chart
Mean	0.82	0.99	1.13	1.27	1.38	1.82
Standard deviation	0.09	0.09	0.08	0.09	0.11	0.12
Range	0.45	0.60	0.40	0.55	0.65	0.35

scores. The laptop VA results at 100° range from 0.2 logMAR above the chart measurement to 0.1 logMAR below the chart reading. The Bland–Altman plot for VA (Fig. 4) shows a low degree of variability, particularly as a number of points lie on the *x*-axis, demonstrating no difference between the tests, but the variation is irrespective of the level of acuity.

Fig. 5 shows that for all subjects the chart produced a higher CS score than the laptop. However, it is also clear that the difference between the two tests is variable across subjects, ranging from 0.3 to 0.95 difference (mean 0.44, standard deviation 0.1), and variable across levels of CS.

Discussion

Given the wide variety of circumstances in which it would be useful to test vision, together with the wide availability of laptop computers and vision-testing software which might be run on them, we wished to investigate the influence that one particular feature of a laptop – the ability to tilt the screen – might have on vision tests. The results suggest that the angle of a laptop screen is a factor which needs to be carefully controlled. In particular, while we found that measures of VA were not systematically affected by screen angle, measures of CS were.

The correlation coefficient of 0.81 for the relationship between the screen angle and CS measurement provides evidence of a strong and linear relationship between the two variables. Also, all the increments between angles,

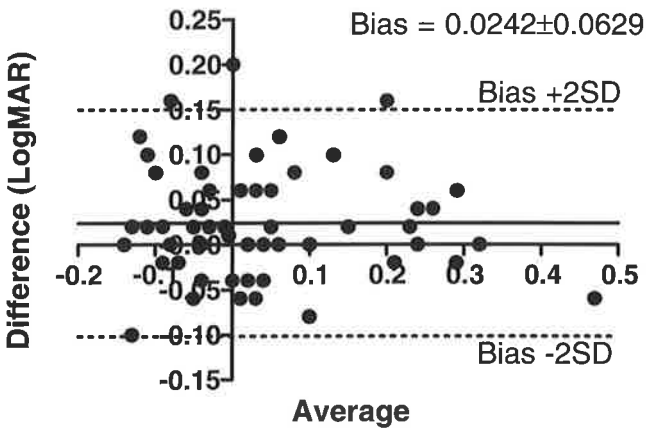

Fig. 4. Bland–Altman analysis of agreement between VA measured with the laptop screen positioned at 100°, and measured with the logMAR chart (Difference = Chart minus Laptop). The unbroken line illustrates the calculated bias (0.02 ± 0.06); dashed lines are bias ±2 SD; 95% limit of agreement: −0.01 to +0.15.

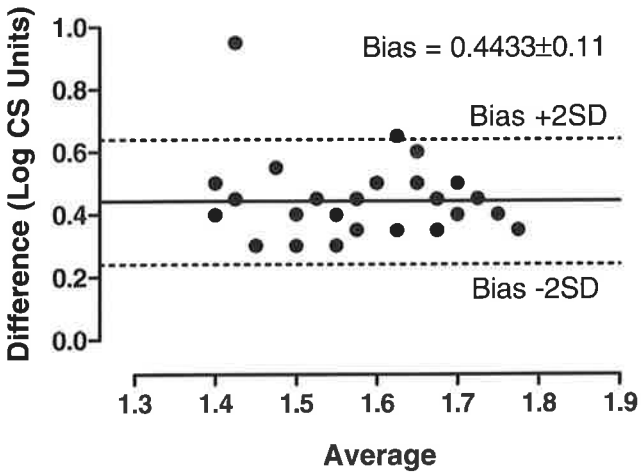

Fig. 5. Bland–Altman analysis of agreement between CS measured with the laptop screen positioned at 100°, and measured with a Pelli–Robson chart (Difference = Pelli–Robson minus Laptop). The unbroken line illustrates the calculated bias (0.44 ± 0.11); dashed lines are bias ± 2 SD; 95% limit of agreement: 0.24–0.65.

from a minimum of 0.11 to a maximum of 0.17 logCS units, are significantly greater than the reported mean test/re-test value for the Pelli–Robson chart of 0.02 (SD ± 0.09),[13] which supports the evidence that the increase in CS is directly related to the change in screen angle. Therefore, in future testing, it will be very important to maintain a consistent screen angle between subjects and to minimise movement of the subject to ensure reliable results.

Whilst the screen angle which gives the closest CS measurement to the Pelli–Robson chart has now been identified (100°) for this laptop, the relationship is variable between the tests. Fig. 3 demonstrates a linear relationship between the laptop CS measurements and the laptop screen angle. The values of slope and intercept of the regression line were used to calculate the angle at which the screen would need to be to produce an equivalent result to the Pelli–Robson chart. The calculation showed that the laptop screen would need to be at an angle of 115°, assuming the relationship remains linear beyond 100°, to produce a CS result of 1.82 logCS units. However, at 115° the visibility of the letters is reduced, thus adversely affecting the measurements.

The Pelli–Robson mean value of 1.82 is within normal limits compared with published normative data of 1.73 to 1.84.[14] Therefore, it can be assumed that the lower CS results with the laptop screen are a true difference between the two measurement methods and not due to a subject group with generally reduced CS. If the bias, as calculated using the Bland–Altman analysis, is constant, i.e. similar across the range of measured values, it might be possible to adjust the values of the laptop measurement simply by adding the mean bias. To determine whether this is feasible, Bland and Altman[12] state that if the mean bias ± 2 standard deviations (upper and lower dotted lines as shown in Fig. 4) is not clinically important, then the two measurement methods can be used interchangeably. It has been shown that when scoring by triplet on the Pelli–Robson chart a difference of 0.3 logCS units would be considered clinically significant.[15] However, when scoring per letter this difference reduces to 0.2.[16] With the laptop, the range (bias –2 SD to bias +2 SD) is greater than this, at 0.25. This suggests that the tests are not interchangeable. The variation between the results recorded with the Pelli–Robson chart and those recorded with the laptop potentially limits the usefulness of using the laptop to test CS. However, if a subject population is being compared with a control group, then it is still possible to determine differences in CS between the groups using the laptop. The problem would arise in the comparing this with normative data.

The VA measurements demonstrated a higher level of agreement between the tests, the mean estimated bias of only one letter (0.02 logMAR) being within the normal test/re-test values (± 0.10) for the ETDRS chart.[17] The maximum difference of 0.2 logMAR is in agreement with the reported 95% limits of agreement in normal eyes of 0.19 logMAR.[18] In addition the bias ± 2 standard deviations (−0.1 to 0.14), although close, does not encompass what is considered to be a clinically significant change of 0.15 logMAR.[19]

During the initial design process of the project it was noticed that there was a reduction in illumination when the laptop was removed from the mains power supply. For this project it was decided to perform the testing using only the battery supply as this provides greater potential portability. However, an additional 5 subjects were assessed with the laptop on both battery and mains power supply. The results from this small sample showed little difference in measurements whether using battery or mains power, with a mean magnitude of 0.06 logCS units (1 subject had a decrease in CS of 0.15 when the power supply was switched to the battery, 1 had no change and 3 had an increase in CS of 0.05). Whilst these initial results are encouraging, further work is needed to determine whether there is any further degradation in illumination if the laptop is run on battery power for a long time.

A further limitation of this study is that only one laptop was used, so due to potential variations in screen characteristics it is not possible to determine whether these conclusions are directly applicable to other laptops. While we have not addressed why the tilt of the laptop screen affects some measurements and not others, it has long been known that contrast drops off from the centre of an LCD screen. The rate of drop-off depends on the depth and width of the LCD cells that comprise the screen. However, our aim here has been to show that issues such as screen angle are important in testing, that there is a need for standardised test procedures (including fixing the screen angle) and that measurements should be interpreted with caution.

In summary, the angle of the laptop screen significantly affects contrast sensitivity measurements but does not systematically impact on the VA results. In addition, there is variability between the laptop and standard clinical tests for both VA and CS. However, the variability in the measurements of VA is within normal limits whereas the CS readings demonstrated a larger degree of variability between the tests. They are therefore not interchangeable. It remains the case,

however, that within the constraints identified here, visual function testing using a laptop could provide useful information when the use of standard clinical tests is not possible. The addition of normative data determined for a user's particular laptop would also enhance the data obtained and resulting conclusions.

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