An assessment of a modern touch-screen tablet computer with reference to core physical characteristics necessary for clinical vision testing

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There are a multitude of applications using modern tablet computers for vision testing that are accessible to ophthalmology patients. While these may be of potential future benefit, they are often unsupported by scientific assessment. This report investigates the pertinent physical characteristics behind one of the most common highest specification tablet computers with regard to its capacity for vision testing. We demonstrate through plotting of a gamma curve that it is feasible to produce a precise programmable range of central luminance levels on the device, even with varying background luminance levels. It may not be possible to display very low levels of contrast, but carefully using the gamma curve information allows a reasonable range of contrast sensitivity to be tested. When the screen is first powered on, it may require up to 15 min for the luminance values to stabilize. Finally, luminance of objects varies towards the edge of the screen and when viewed at an angle. However, the resulting effective contrast of objects is less variable. Details of our assessments are important to developers, users and prescribers of tablet clinical vision tests. Without awareness of such findings, these tests may never reach satisfactory levels of clinical validity and reliability.

1. Introduction

Technological advances have led to the development of powerful yet portable tablet computers whose touch-screen resolutions now permit the presentation of targets small enough to test the limits of normal visual acuity. The vast commercial catalogue of wide-ranging applications (‘apps’) has inevitably included many for testing visual function, and, indeed, our own pilot studies have demonstrated the potential ease of interactivity with such touch-screen computers for vision testing, even among older patients with ophthalmic disease.

Visual function assessment is fundamental to all hospital ophthalmological management, and a drive towards home vision testing has been stimulated by the challenges of an ageing population and the increasing socio-economic burden of hospital care. Age-related macular degeneration (AMD), for example, is the leading cause of blindness in the UK [1] and has a huge impact on patients’ independence and quality of life [2]. A sensitive, easy and objective means of regularly assessing at-risk patients for conditions such as this in their own homes would have incredible potential to reduce some of the burden of essential hospital visits and facilitate more rapid access to hospital care of those found to be at high risk.
However, physical characteristics of the modern tablet computer screen displays that are fundamental to utilization for clinical vision testing have not yet been assessed. The ability to control luminance and more specifically to produce contrast levels reliably in defined screen and observer locations, across the range of human sensitivity, should be assessed for all displays used for vision assessment. These properties should be confirmed with regard to the specific likely mode of use of tablet computers, acknowledging likely viewing distance and angles as well as screens being switched on and off. Other physical screen attributes will invariably be of relevance, but knowledge of the core characteristics above should be a prerequisite to development of vision testing applications, dictating their design and intended scope.

Of course, beyond this assessment, studies should assess a range of screens, with consistency assessed across different manufacturers, models and units. Once the tests are developed, they must be tested in a clinical setting with constant background luminance and constant distance from the patient to the visual target, to produce evidence for clinical validity and reliability. All these steps are underlined by the first, core physical criteria—defects in this are unlikely to support valid and reliable clinical tests unless they are understood and accounted for.

This report will describe fundamental physical characteristics pertinent to visual function testing with a common, modern touch-screen tablet computer (iPad 3, Apple Inc.). The most recent incarnations of this device have resolutions that are able to interrogate the normal limits of human acuity resolution—an iPad 3 with resolution 2048 $\times$ 1536 pixels and screen size 19.6 $\times$ 15.1 cm allows testing 1.0 min of visual angle subtended per pixel at a viewing distance of 33 cm. Further crucial physical characteristics, however, have not yet been demonstrated. We will discuss our assessment of such characteristics and the importance and relevance of our findings to developing applications for clinical assessment of vision with such a device.

2. Methods

The device was programmed using an Apple MacBook Pro (Apple Inc.) running Adobe CS v. 5.5 with FLASH and ACTIONSCRIPT v. 3.0 (Adobe Inc.) by T.M.A. and supported by a professional computer programmer. Settings were adjusted so that auto-adjust was switched off, and mains power was connected.

Luminance measurements were obtained by mounting the tablet in a vertical position 33 cm from the aperture of a PR650 photospectroradiometer (Photo Research, Inc., Chatsworth, CA). The apparatus was housed in a psychophysics laboratory with all lighting switched off. The angle to the photometer was controlled using a precisely mounted protractor to determine the effects of viewing angle on luminance.

Michelson contrast was defined as

$$C = \frac{L_{\text{max}} - L_{\text{min}}}{L_{\text{max}} + L_{\text{min}}},$$

where $L_{\text{max}}$ represents the highest luminance and $L_{\text{min}}$ represents the lowest luminance. Weber contrast was defined as

$$L = \frac{L_{b} - L_{\text{min}}}{L_{b}},$$

where $L$ represents the luminance of the features and $L_{b}$ represents background luminance.

The experimental protocol investigated three key areas.

2.1. Investigation 1: gamma function assessment and range of programmable contrasts

Derivation of a gamma function curve is an important calibration step for any device intended for visual function testing. It is essential to be able to code and decode luminance values for the screen display. The tablet device has eight-bit greyscale-programmable resolution (pixel values 0–255); to calibrate it, a central white square was presented at intervals of 32 programmable pixel intensities between 0 (black) and 255 (maximum). Luminance was measured for each of these nine programmed values. The seven values between each calibrated point were thereafter calculated by linear interpolation, creating a gamma function that was fed into a look-up table. To check on the potential interaction between different areas of the screen, the nine luminances were presented on the backgrounds of 0, 63, 127, 191 and 255 pixel intensity values. The changes in background luminance were to ensure that specified target luminance was independent of target background.

The gamma function curve from this investigation was used to derive the potential range of display of contrast targets on this device. As the device is eight-bit, the possible contrasts that can be displayed are inevitably limited. The luminances that would be required to construct sinusoidal gratings or black-on-white letters of various mean luminances and contrasts were determined. Using the look-up table, we rounded these to the nearest actually available luminance on the tablet computer and derived the practically achievable contrasts. We compared these practically available contrasts on this tablet device with those used in two gold-standard chart-based screening tests, the VisTech chart (Vision Sciences Research Corporation, San Ramon, CA) and the Pelli Robson Contrast Sensitivity chart (Haag–Streit USA, Mason, OH).

2.2. Investigation 2: effective time to stability of display screen after switching on

The period of time from switching on the display to when the luminance values on the screen stabilize is a crucial aspect of visual testing that could affect validity and reliability of clinical testing if not accounted for. It is particularly important for such a portable device that might be used away from standard clinical or psychophysical settings. The device was switched off for 1 min. Luminance was measured after switching back on until it stabilized. We repeated this for ‘off’ times of 5, 10 and 30 min. We also switched off the computer overnight and recorded central set luminance values the next day, over time until they stabilized.

2.3. Investigation 3: consistency of luminance and contrast of targets at different locations on the tablet screen and different angles of view

It is acknowledged that even in cathode ray tube (CRT) monitors luminance varies towards the edges of the screen [3], typically by around 30 per cent [4]. Tablet vision tests may involve large proportions of the screen and expect the tested person to be at close range. We programmed the tablet computer to display target squares in each of the corners of the tablet screen. We set the photometer to perpendicularly measure luminance of the target squares and their background luminance values at each of these corners. Next, we measured luminance for these targets and their background luminance with the photometer angled towards each of them from a fixed central position 33 cm away from the screen. This was to simulate the effect of a patient positioned centrally to view both central and peripheral targets, as a likely clinical testing scenario, incorporating the potential effect...
3. Results and discussion

3.1. Investigation 1: luminance measurements

Figure 1a illustrates the gamma function for the device for five backgrounds. Note that the data for the five backgrounds superimpose almost exactly, so that it is not possible on this scale to see any effect of background, highlighting the minimal effect on the central luminance of changing the background luminance. The small effects that are present are most pronounced at the maximum and minimum background luminances and these are illustrated in the expanded insets in figure 1a. There is a measurable, but very small, increase in the actual measured luminance (dotted line) compared with the expected target luminance at low luminances and a small decrease at high luminances. At its worst, the interaction between target and background described was 0.0045 or less than 9 per cent of 1 dB. The commonly accepted just-noticeable difference for contrast difference detection is around 1 dB. We can therefore conclude that the measurement discrepancy induced when the background is at maximum will not affect contrast thresholds.

The corresponding look-up table from this investigation allows for any required luminance to be produced by providing the programmable pixel intensity for the required output luminance. Finally, it allays concerns relevant to CRT displays in that variations in background intensity have any significant effect on foreground intensity.

Figure 1. (a) Gamma function curve for nine luminances of a central area with five background luminances. The programmable-greyscale values on the x-axis produce predictable and regular luminances according to the curve displayed. (b) Available contrasts on the tablet computer compared with standard VisTech and Pelli–Robson charts. Where contrast resolution meant that fewer than five greyscale value 

We used the derived look-up table to demonstrate an available contrast range for the device to compare with standard commonly used VisTech [5] and Pelli–Robson charts. Figure 1b illustrates the available contrast range for the device compared with the chart-based vision tests. Available contrasts on the tablet computer are shown for gratings with a mean luminance of 200 cd m$^{-2}$ (Michelson contrast) and black letters on a 200 cd m$^{-2}$ white background (Weber contrast).

The results demonstrate that the tablet screen is unable to exactly match the very low levels of contrast of the Pelli–Robson chart, and tests should not depend on this. However, the results obtained are close to these standards (figure 1b) and, with knowledge of the gamma function curves, it should still be possible to screen for contrast sensitivity deficits over a range of spatial frequencies.

3.2. Investigation 2: effective time to stability of display screen after switching on

If the tablet computer is started from completely cold, after being switched off for 24 h, then the measured luminance of a set target value is initially higher than expected. This reduces over time and stabilizes to its expected value within around 15 min. If the period of time switched off is reduced, so is the time taken to reach stability once it is switched on again. At 30 min switched off, the time to stability was approximately 7 min; at 10 and 5 min switched off values stabilized in 6 min; and with just 1 min of switch off, 1 min was required before screen stability was recovered. In all these scenarios, percentage error was minimal but, for optimum performance, these results show that it is advisable to ensure that the tablet computer is switched on for 15 min before testing to maximize accuracy of luminance values produced when testing vision. The stability of the screen was also observed with the device unplugged and running on battery charge only; luminance values were found to be extremely stable right up until imminent automatic device shutdown.

3.3. Investigation 3: consistency of luminance and contrast of targets at different locations on the tablet screen and different angles of view

We first assessed variations in luminance and contrast respectively at different locations on the tablet screen measured perpendicularly with a photometer. Luminance varied from $-5$ to $-23$ per cent compared with central values. Background luminance values also changed correspondingly, however,
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References

uniformity over the whole screen, with our particular test screen than to the left. It is clear that there is considerable non-uniformity over the whole screen, with our particular test screen.

There was a greater reduction in luminance to the right of the screen, and, on this particular tablet computer screen, an expected reduction in luminance towards the four corners of the screen, and, on this particular tablet computer screen, there was a greater reduction in luminance to the right of the screen than to the left. It is clear that there is considerable non-uniformity over the whole screen, with our particular test screen.

model demonstrating right of the screen showing greater discrepancy relative to the left. However, these changes are consistent for foreground and background, so that the percentage impact on contrast of targets is minimal, typically around 1 per cent.

We next assessed the more pertinent clinical situation of a patient located centrally viewing any peripheral targets. Figure 2 illustrates variance in luminance owing to changed viewing angle to a target as well as the peripheral location of targets. Again, absolute changes in luminance are high in this scenario but contrast levels remain remarkably stable with minimal significant impact on clinical testing. It is evident, however, that variations in viewing angle should be kept to a minimum for vision testing applications.

4. Conclusions

Although there are major challenges in identifying and validating specific visual function tests to assess disease activity, it would be of enormous significance to develop home vision measures sensitive to AMD lesions. Other conditions that might benefit from home testing include diabetes and patients with retinal vein occlusions. The data presented above represent the first published examination of physical characteristics for a modern tablet computer that are pertinent to the display of targets for vision testing. Such investigation findings may not be noticeable to typical users of such computers but are of importance to visual psychophysical testing and must be borne in mind when developing vision tests on any tablet computer and instructing patients on their use. Further studies would be needed to demonstrate whether this information could be extrapolated to different versions of the same device as well as different makes of tablet computer. Although this study has such limitations, it provides information that is the first step towards greater confidence in designing clinical visual function tests on tablet computers and represents a foundation for future development.


Figure 2 Variations in luminance and contrast at different locations on the tablet screen measured as if an observer were viewing all peripheral targets from a central location. Values within the white circles in each of the four corners represent percentage change, relative to the centre of the screen, of a set foreground luminance (top value) and background luminance (middle value). The bottom value in each of the circles is the percentage change in calculated contrast.

such that, overall, percentage change in contrast relative to the centre varied only between $-1.2$ and $+0.5$ per cent. There was an expected reduction in luminance towards the four corners of the screen, and, on this particular tablet computer screen, there was a greater reduction in luminance to the right of the screen than to the left. It is clear that there is considerable non-uniformity over the whole screen, with our particular test screen.


References


