

## Quantification of Color Vision Using a Tablet Display

Alicia Chacon; Jeff Rabin; Dennis Yu; Shawn Johnston; Timothy Bradshaw

- BACKGROUND:** Accurate color vision is essential for optimal performance in aviation and space environments using nonredundant color coding to convey critical information. Most color tests detect color vision deficiency (CVD) but fail to diagnose type or severity of CVD, which are important to link performance to occupational demands. The computer-based Cone Contrast Test (CCT) diagnoses type and severity of CVD. It is displayed on a netbook computer for clinical application, but a more portable version may prove useful for deployments, space and aviation cockpits, as well as accident and sports medicine settings. Our purpose was to determine if the CCT can be conducted on a tablet display (Windows 8, Microsoft, Seattle, WA) using touch-screen response input.
- METHODS:** The CCT presents colored letters visible only to red (R), green (G), and blue (B) sensitive retinal cones to determine the lowest R, G, and B cone contrast visible to the observer. The CCT was measured in 16 color vision normals (CVN) and 16 CVDs using the standard netbook computer and a Windows 8 tablet display calibrated to produce equal color contrasts.
- RESULTS:** Both displays showed 100% specificity for confirming CVN and 100% sensitivity for detecting CVD. In CVNs there was no difference between scores on netbook vs. tablet displays. G cone CVDs showed slightly lower G cone CCT scores on the tablet.
- CONCLUSIONS:** CVD can be diagnosed with a tablet display. Ease-of-use, portability, and complete computer capabilities make tablets ideal for multiple settings, including aviation, space, military deployments, accidents and rescue missions, and sports vision.
- KEYWORDS:** color vision, vision testing, tablet displays.

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Hereditary color vision deficiency (CVD) is a common condition in 8% of males and 1 in 200 (0.5%) of females. CVD also can be acquired as an early sign of ocular, systemic, and/or neurologic disease.<sup>3,4</sup> It is well-established that CVD can increase error rate and reaction time in cue-limited settings where accurate color discrimination is essential for critical tasks. Cue-limited settings span a vast range, including discrimination of signal lights, color-coded displays, physicians' judgments of skin tone, retinal colors, as well as elderly and visually impaired patients discriminating the colors of their pills.<sup>1,2,5</sup> Many color tests detect CVD but fail to diagnose type and severity of CVD, critical for linking performance to occupational demands and for monitoring disease-related acquired CVD over time. The Cone Contrast Test (CCT; Innova Systems, Inc., Moorestown, NJ) identifies type and severity of hereditary<sup>6,8,9</sup> and acquired<sup>7</sup> CVD and agrees with gold-standard tests such as the anomaloscope.<sup>6,8</sup>

The CCT is displayed on a netbook computer suitable for administration in most clinical environments. However, a more portable CCT may prove useful in austere settings such as aviation and space cockpits and related settings, military deployments, accident and trauma assessments, as well as occupational, health and school screenings. Hence our purpose was to determine if normal and abnormal color vision can be accurately diagnosed with the CCT on a portable tablet display (Windows 8 tablet, Microsoft, Seattle, WA) with a touch screen interface.

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## METHODS

### Subjects

The CCT was assessed in 16 CVN and 16 CVD subjects recruited from university students, faculty, patients, and staff. Informed consent was obtained in accord with our IRB approved protocol. Subjects were confirmed to be CVN or CVD based on Ishihara, Dvorine, and HRR pseudo-isochromatic plate testing.

### Stimulus

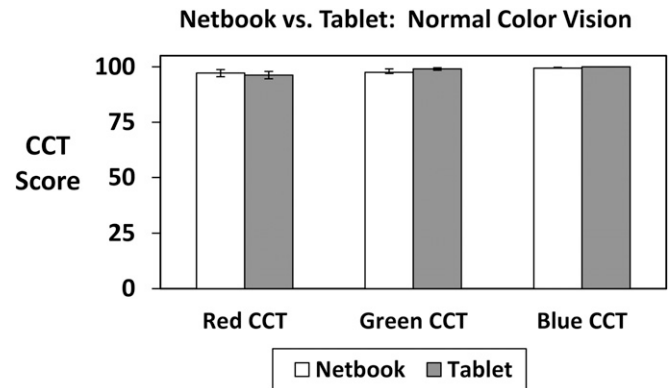
The CCT displays colored letters on a gray background which are visible only to R, G, or B cones. A single letter appears in the center of the screen and the observer uses a mouse to select the letter seen from an adjacent 10-letter matching display. A staircase program, like a hearing test, adjusts color contrast up and down, based on the observer's correct or incorrect responses, to determine the lowest (least visible) R, G, and B cone contrast the patient can see. R, G, and B cone CCT scores are expressed on a scale of 0 to 100 based on the number of letters identified correctly. CVNs typically score 90 or above and hereditary CVDs score < 75. Scores between 75 and 90 suggest acquired CVD from ocular, systemic, or neurologic disease and/or trauma to the eye or brain.

### Procedure

Subjects were tested with both the netbook computer CCT (10.1" screen, 1024 × 600 pixels, Windows 7) and tablet display CCT (10.1", 1366 × 768 pixels, Windows 8) in counter-balanced order to minimize learning effects. A custom program designed for use with the Datacolor Spyder™ colorimeter (Datacolor, Lawrenceville, NJ) was used to quantify both netbook and tablet display luminance and CIE chromaticity, transform these values to cone excitations, and convert them to R, G, and B cone contrasts as specified in previous CCT publications.<sup>6-8</sup> Cone contrast levels for each display were within tolerances specified for the netbook display. For the netbook each subject used a mouse to select letters seen from the adjacent matching display and for the tablet each subject used the touch-screen to select letters from the matching display. For both displays testing was conducted in a dark room with display parallel to the face plane. The netbook was 36 inches away subtending a diagonal angle of 15.7° at the eye, while the subject positioned the tablet at her/his desired distance within 61–91 cm (24–36 in) away, since it was anticipated that the tablet would be used at near distances suitable for each specific patient and setting. The average of right and left eye CCT scores from each subject was used for analysis to reflect between-eye CCT differences due to differences in cone distribution and/or photopigment density.

### Statistical Analysis

Parametric descriptive and comparative statistics were used to describe central tendencies and both within and between group differences using two-way ANOVA and post hoc *t*-tests.

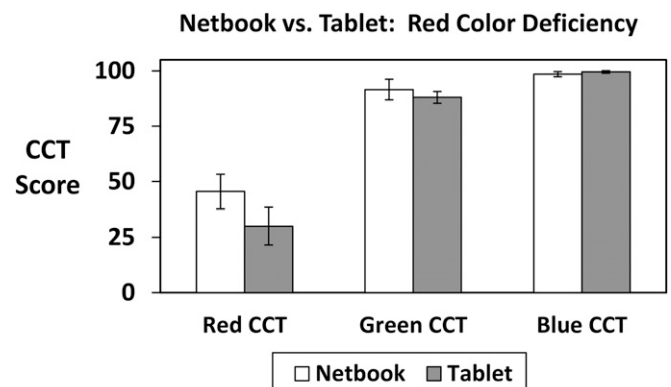


**Fig. 1.** Mean CCT scores ( $\pm 2$  SE) are shown for netbook and tablet displays for 16 color vision normal participants.

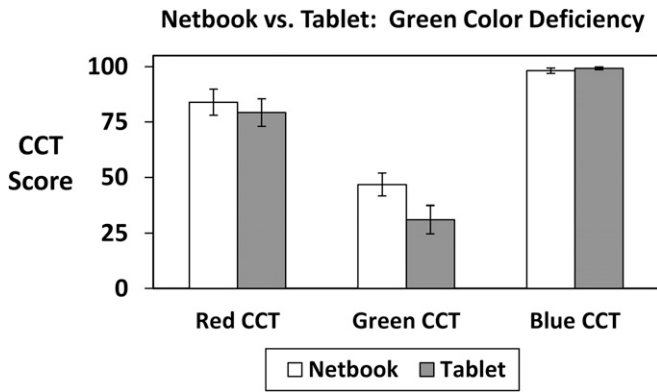
## RESULTS

Both netbook and tablet displays showed 100% specificity for confirming normal color vision in CVN subjects, with all subjects scoring 90 or higher on R, G, and B CCTs. As shown in **Fig. 1**, there was no difference between CCT scores obtained with netbook and tablet displays in CVN subjects (2-way repeated measures ANOVA:  $F(1,90) 0.43, p = 0.52$ ). For both displays mean B cone CCT scores (99.8) were higher than G (98.6) and R (96.4;  $F(2,90) = 17.60, p < 0.0001$ ). These small differences are most likely due to the fixed contrasts selected for the CCT to optimize specificity and sensitivity in military and occupational settings.

As illustrated in **Fig. 2** and **3**, both netbook and tablet displays showed 100% sensitivity for detecting color deficiency in CVD subjects with an average score of 39 (range: 10–65) on the CCT for colors corresponding to the CVD. **Fig. 2** shows that R cone (protan) subjects showed a selective decrease on the R cone CCT [2-way repeated measures ANOVA:  $F(2,24) = 100.92, p = 2.1 \times 10^{-12}$ ], but there was no significant difference between R cone CCT scores on netbook and tablet displays [ $F(1,24) = 2.50, p = 0.13$ ]. **Fig. 3** illustrates that G cone CVDs showed a selective decrease on the G cone CCT [ $F(2,60) = 259.53, p = 12.9 \times 10^{-30}$ ] and G cone scores were lower



**Fig. 2.** Mean CCT scores ( $\pm 2$  SE) are shown for netbook and tablet displays for 5 red cone (protan) color vision deficient participants.



**Fig. 3.** Mean CCT scores ( $\pm$  2 SE) are shown for netbook and tablet displays for 11 green cone (deutan) color vision deficient participants.

on the tablet compared to the netbook display [ $t(10) = 5.38$ ,  $p = 0.0003$ ].

**DISCUSSION**

The CCT diagnoses type and severity of hereditary CVD with sensitivity and specificity comparable to the anomaloscope, which is considered a “gold standard” for diagnosis of red-green color deficiency.<sup>6,8,9</sup> The CCT also detects acquired CVD in conditions which span levels of the visual system.<sup>7</sup> While the current CCT is displayed on a netbook computer with commercial versions available on larger displays, the results of this study confirm that the CCT can be accurately administered on a tablet display, such as Windows 8, using a touch-screen interface at a user-preferred, near test distance. The tablet showed 100% sensitivity for diagnosis of CVD and 100% specificity for confirming normal color vision and provided a quantitative score of severity. All 16 CVD subjects were accurately diagnosed as protan or deutan CVD and all 16 CVN subjects were confirmed to have normal color vision. However, the tablet yielded slightly lower CCT scores in G cone CVDs and a similar trend in R cone CVDs for the color corresponding to their CVD. This was not explicable by display luminance which was comparable for netbook ( $55.4 \text{ cd} \cdot \text{m}^{-2}$ ) and tablet ( $62.4 \text{ cd} \cdot \text{m}^{-2}$ ) gray backgrounds, though CIE chromaticity differed slightly (netbook gray:  $x = 0.269$ ,  $y = 273$ ; tablet gray:  $x = 0.31$ ,  $y = 0.35$ ). However, cone contrasts relative to these backgrounds were matched for the two displays within specified tolerances. The difference may reflect: 1) higher screen resolution afforded by the tablet display, which minimizes pixel-based artifacts which may enhance performance on the netbook; 2) inexperience with the tablet touch screen vs. the

netbook mouse-response such that some subjects did not invest full effort at threshold; and 3) minor variation in letter size and/or contrast on the tablet display due to variation in test distance. Although CVD severity was, on average, greater with the tablet, sensitivity for detection of CVD and specificity for confirming CVN were 100% for each display for this initial sample of subjects.

In conclusion, the CCT can be conducted on a tablet such as Windows 8 to detect hereditary CVD. The tablet provides a highly portable platform with complete computer capabilities suitable for austere settings such as space and aviation cockpits, military deployments, vision screenings, laser eye injury, as well as accidents and sports vision applications. The tablet CCT is readily administered to the patient in the exam chair and may be used for home monitoring with results saved for wireless conveyance to medical records. Superior screen resolution and resistance to off-axis viewing make the tablet suitable for myriad settings to enhance detection of hereditary and acquired CVD with major goals of preserving vision and improving safety.

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