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Beyond 20/20: New Clinical Methods to Quantify Vision Performance

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ABSTRACT Objective: To describe the design, the sensitivity, and the application of new methods to quantify visual performance. Methods: The super vision test–night vision goggle (SVT–NVG) is a new clinical letter chart that measures high- and low-contrast vision under daytime and simulated night conditions. The cone contrast test (CCT) is a computer-based color test that readily diagnoses type and severity of color deficiency. Results: The SVT–NVG reveals subtle decrements from normal not detected by standard visual acuity. The CCT shows 100% sensitivity for the detection of hereditary red or green color deficiency and reveals acquired deficiency as an early sign of disease. Conclusions: The SVT–NVG and CCT provide rapid, sensitive indices of color and spatial vision potentially linkable to real-world operational demands.

INTRODUCTION

The growing demands of global conflict, the preeminent role of night vision, and the increasing use of color symbology on displays necessitate clinical tests predictive of real-world performance. Although existing "gold standard" tests, such as visual acuity (VA) and pseudoisochromic plate (PIP) color vision testing books, determine pass/fail performance, conditions such as refractive error, eye surgery, cataracts, keratoconus, color deficiency, medications, fatigue, etc. can degrade operational visual performance despite passing scores on current standard vision tests. This is especially true under impoverished environmental visual conditions such as smoke, fog, haze, glare, dusk, and night. We describe new clinical tests that rapidly and accurately quantify multiple aspects of vision performance, including high- and low-contrast acuity, night vision, and color discrimination.

The super vision test–night vision goggle (SVT–NVG) is a vision chart designed to assess high- and low-contrast vision under normal and simulated NVG conditions. The SVT–NVG includes an extended VA range (20/32–20/5; 4× smaller than "20/20") and low-contrast (contrast sensitivity) letters to detect exceptional "super" vision and subtle decrements from normal. When viewed through the dark green (NVG) filter, the test simulates the color, the brightness, and the visual challenge of NVGs.

The cone contrast test (CCT) is a computer-based color test that rapidly identifies type (red, green, or blue) and severity (mild, moderate, and severe) of hereditary color deficiency, quantifies color performance in color normals, and detects acquired color deficiency early in eye, systemic and neurologic disease, and color vision loss from hypoxia, laser injury, and medications.

This article reviews test design, specificity, sensitivity, and application of the SVT–NVG and CCT. These novel tests promise to enhance selection, performance, and safety and ultimately contribute to the development of new standards for low contrast, night vision, and color performance.

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METHODS

The SVT–NVG chart (Precision Vision, La Salle, Illinois) developed at the USAF School of Aerospace Medicine is illustrated in Figure 1. The top half consists of a high-contrast VA chart with letters ranging in size from 20/32 to 20/5 and letter size decreasing in logarithmic steps (26% smaller per row). This design, developed by Bailey and Lovie,[1] assures a constant task regardless of VA level and consistent change in letter size. Inclusion of letters smaller than 20/10 (20/6.3 and 20/5) allows detection of "super" vision anticipated with refractive surgical procedures designed to correct or minimize optical aberrations. The bottom half of the SVT–NVG is used to assess low-contrast vision. The two small-letter contrast sensitivity charts are highly sensitive in assessing overall visual function and have been successfully used to detect vision abnormalities among pilot-training applicants and trained aircrew.[2–8]

Normal color vision depends on three types of retinal cones sensitive to red, green, or blue (R, G, or B) light. Hereditary color vision deficiency (CVD; 8% of males and 1 in 200 females) is due to a lack of either R cones (protanopia in 1% of males) or G cones (deuteranopia in 1%) or due to a shift in cone sensitivity (protanomaly, R shifted toward G in 1% and deuteranomaly, G shifted toward R in 5%).[9,10] There are numerous color vision tests (e.g., pseudoisochromatic or PIP book tests) that detect the presence of CVD, but few indicate the type (R, G, or B) or severity of CVD, critical parameters for linking color ability to occupational demands. The computer-generated CCT detects CVD type and quantifies severity by presenting a series of reddish, greenish, and bluish letters visible only to R, G, or B cones, respectively.[11–13] Each letter appears briefly (1–1.6 seconds) centered within a cross-hairs on a grey background, and the subject is required to read the letter aloud. The program presents a different (random)

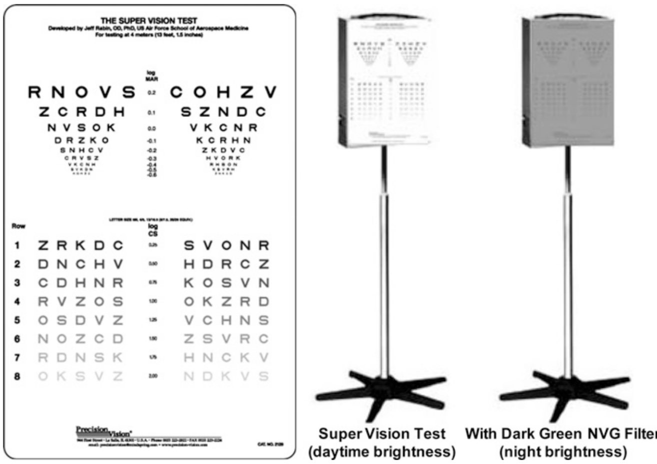
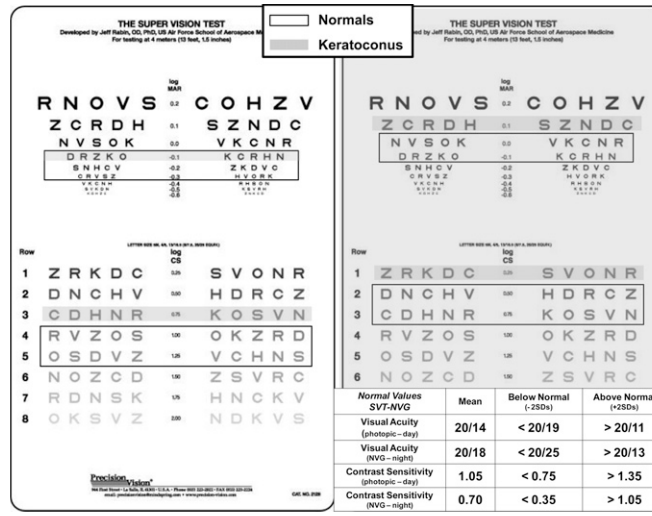


FIGURE 1. SVT–NVG. The translucent letter chart is back-illuminated by a fluorescent light box and viewed in a dark room at 4 m (13 ft.). The top assesses high-contrast vision with letters ranging from 20/32 down to 20/5; the bottom measures low-contrast vision (contrast sensitivity). Two different sequences are displayed for right and left eyes. The dark green filter (in gray on the right) simulates the low light level and green color of a NVG display.



Normal Values SVT-NVG	Mean	Below Normal (-2SDs)	Above Normal (+2SDs)
Visual Acuity (photopic – day)	20/14	< 20/19	> 20/11
Visual Acuity (NVG – night)	20/18	< 20/25	> 20/13
Contrast Sensitivity (photopic – day)	1.05	< 0.75	> 1.35
Contrast Sensitivity (NVG – night)	0.70	< 0.35	> 1.05

FIGURE 2. SVT–NVG normative values and results for keratoconus. The clear rectangles show range for visually normal observers; shaded rows represent median performance for keratoconics. The inset table on the bottom right shows normative values. See text for further details.

letter sequence to each subject. A pre-printed score sheet showing the sequence is used by a technician to record the letters missed. The number of errors is entered into the CCT program, which stores and prints R, G, and B cone scores using an intuitive 100-point scale based on cone contrast. Hence, the CCT rapidly provides R, G, and B color ability scores potentially applicable to real-world color demands.

We report retrospective clinical findings showing effective application of the SVT–NVG and CCT for the detection and diagnosis of ocular conditions in the aircrew population. In accord with the Declaration of Helsinki, this retrospective study and the data reported herein were authorized by an exempt protocol approved by our Institutional Review Board.

RESULTS

Figure 2 shows normative values for the SVT–NVG and results for patients with keratoconus, a hereditary corneal dystrophy characterized by progressive corneal steepening and thinning that causes visual distortion. For each test, the letters bounded by the clear rectangular boxes illustrate the mean ± 2 SD for visually normal adults (n = 115), and the shaded rows are median values for keratoconus (n = 36; 60 eyes). On the high-contrast VA test (top left), median performance of keratoconics (shaded row) is within the normal range (within the clear rectangle); all are achieving VA of at least “20/20” and therefore satisfying the current high-contrast standard. However, on the low-contrast test (contrast sensitivity; bottom left, Fig. 2), keratoconic performance is below normal (shaded row above clear rectangle), indicating that in this condition increased contrast is needed to achieve letter recognition. A comparable result was obtained for low-light, NVG filter testing shown on the right side of Figure 2; keratoconic performance is outside normal limits on low-light tests (shaded rows above the clear rectangles). These results showing decreased contrast sensitivity and low-light (NVG) performance exemplify the importance of testing vision at low contrast and under reduced lighting conditions, which characterize the operational environment. The inset table on the bottom right of Figure 2 shows SVT–NVG normal values based on the initial validation study (n = 20) and follow-on application in pilots and aircrew (n = 95).

Figure 3 shows CCT scores, right eyes plotted against left eyes, for a large number of color vision normal (n = 1,263) and CVD individuals (n = 308). The filled boxes with error bars in the top right corner of the plot represent R, G, and B CCT means (±2 SD) for the normal population. Individual results are plotted for R, G, and B cone CVDs. It is clear from Figure 3 that R, G, and B cone CVDs are well below the normal limits on R, G, and B cone tests, respectively. A range of CVD severity is indicated by the range of CCT scores, a potentially useful metric for linking different color abilities to specific occupational demands. CCT sensitivity for detecting hereditary CVD has proven to be 100% when compared to the gold-standard Rayleigh anomaloscope and exceeds the sensitivity of PIP testing in pilot applicants.[13] The CCT technique also proved to be more sensitive than the FM 100 Hue test for the detection of hereditary CVD[11] and has proven effective for the detection of acquired CVD in various disease spanning levels of the visual system.[12] CCT specificity (percent of normals confirmed to be color vision normal) has exceeded 99% with few false positive results.[13]

DISCUSSION

Superior vision is needed for optimizing performance on critical tasks such as pilot duties, target detection, weapons firing,

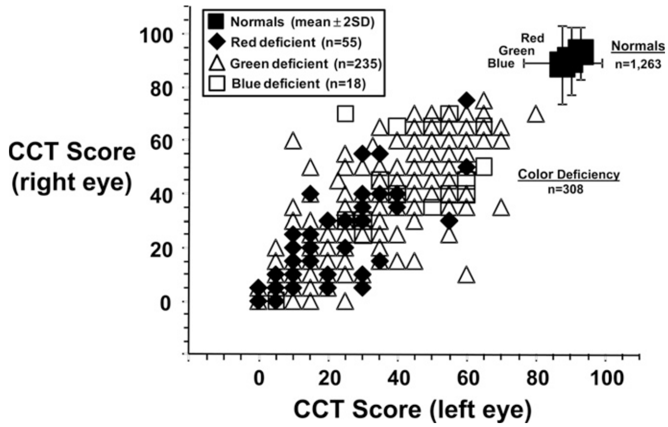


FIGURE 3. CCT scores from the right eye are plotted against the left eye for a large number of color-normal and color-deficient individuals. See text for further details.

night operations, and surgical and medical care.[14–22] Vision standards currently utilized in military settings detect discrepancies from normal but may fail to identify subtle anomalies, such as optical imperfections, early cataracts or keratoconus, or acquired or hereditary color deficiency, which can degrade performance and threaten safety. Operational stressors such as reduced lighting; limited visibility from smoke, fog, and/or unfamiliar terrain; and altitude, fatigue, and emotional stress can further impair performance and safety. Clinical tests that address unique demands of operational settings, such as low contrast, reduced lighting/night vision, and critical color discriminations in the absence of redundant cues, are needed. Moreover, clinical measures that identify exceptional visual ability are highly desirable for selection and retention.

The new tests described herein venture beyond "20/20 VA" to offer new metrics for quantifying spatial and color vision. The SVT–NVG provides clinically expedient measures of high- and low-contrast vision under daytime and low-light (simulated NVG) conditions. The CCT provides a numerical score of color ability specific to R, G, and B cone vision. Color deficiency is detected unequivocally, categorized (R, G, or B cone), and graded in terms of severity.

These new methodologies enhance sensitivity for detecting decreased performance while retaining high specificity for confirming normal vision and for identifying enhanced capabilities. Nevertheless, definitive linkage between clinical testing and operational performance remains to be determined. The U.S. Air Force Operational Based Vision Assessment Program is utilizing unique high-fidelity display methodologies to define relations between visual performance and operational demands. The SVT–NVG and CCT are formative initial steps in the same direction.

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