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Dynamic Visual Performance: Comparison Between Helmet-Mounted CRTs and LCDs (Reprint)

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Dynamic visual performance: Comparison between helmet-mounted CRTs and LCDs

Jeff Rabin
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Abstract-- A methodology is demonstrated for evaluating dynamic visual performance by comparing a helmet-mounted cathode-ray-tube (CRT) display with a liquid-crystal display (LCD). The miniature CRT contained in the Integrated Helmet and Display Sighting System (IHADSS) used in the AH-64 Apache helicopter was compared to a head-mounted active-matrix LCD (AMLCD) currently under development. Dynamic visual performance was assessed by measuring flicker detection, target recognition vs. duration, and target recognition vs. velocity in five subjects tested with each display (two-way repeated measures design). At low-to-moderate rates of stimulus presentation, there was no significant difference in dynamic visual performance between displays. However, at higher rates of presentation (flicker frequency greater than 4 Hz, target velocity greater than 4 deg/s, target duration less than 250 ms), dynamic visual performance was significantly reduced when using an LCD compared to a CRT ($p < 0.01$). These visual-performance differences, which were not explicable by display differences in luminance, color, or spatial resolution, reflect differences in the capacity of each system to generate imagery of sufficient contrast at high rates of presentation. Implications for selection and development of visual displays for use in aviation and related fields are considered.

Keywords -- *Cathode-ray tube, dynamic visual acuity, liquid-crystal display, temporal response.*

1 Introduction

The majority of video imagery, including television, video games, and computer-generated text and graphics, is displayed with cathode-ray-tube (CRT) technology. CRTs, which utilize an electron beam, deflection system, and phosphor screen, produce images with high spatial, temporal, and chromatic resolution,[1,2] Currently, CRT technology is used in some helmet-mounted display systems for military aviation. However, CRT components consume significant power, generate heat, and are heavy and large. Despite high resolution, the considerable weight, size, and power consumption of CRTs have limited their applicability as portable devices.

Flat-panel technology provides an alternative display medium for conveying visual information electronically.[2,3] These displays have the potential to consume less energy, generate less heat, and are lighter and thinner, therefore occupying less volume than CRTs. Flat-panel displays (FPDs) are being used increasingly in applications requiring portability, longevity, and minimum utilization of space. Several systems under development for the military will use miniature FPDs. These systems include helmet-mounted displays in which an enhanced image is viewed directly, or symbology is superimposed on a real-world scene. The ultimate goal of these efforts is to improve battlefield command and control, communications, lethality, and survivability.[4]

Notwithstanding the potential applications of flat-panel technology, there are few studies of visual performance with these displays, probably due to the limited availability of systems for testing. Anecdotal reports have suggested possible problems with dynamic imagery on LCDs. Potential limitations should be identified during development so that the final product affords maximum performance and safety on the battlefield.

The purpose of this study was to demonstrate a methodology for evaluating dynamic visual performance by comparing a helmet-mounted CRT display to an LCD under development. The LCD was on loan from Honeywell Corp. for our preliminary evaluation and to help us develop techniques of testing. Flicker detection, target recognition *vs.* duration, and target recognition *vs.* velocity were used to reveal differences in dynamic visual performance between systems. Implications for selection and development of visual displays are considered.

2 Method

Subjects. Five subjects (two females and three males, ages 24-34) recruited from laboratory personnel volunteered their participation in this study. All subjects had normal ocular health and binocular vision with corrected visual acuities of at least 20/20 in each eye. The subjects wore their refractive correction during testing, and were instructed on proper focus adjustments. All subjects gave their informed consent after protocol approval by institutional review committees.

Apparatus. The CRT evaluated was the miniature CRT used in the Integrated Helmet and Display Sighting System 0HADSS, Honeywell Corp., Fig. 1) for the AH-64 Apache helicopter. This is a monocular, helmet-mounted system, which consists of a miniature CRT (P43 green phosphor), optical elements, and see-through combiner lens on which imagery and symbology are displayed. While the imagery is normally derived from a forward-looking infrared (FLIR) sensor mounted to the nose of the aircraft, in the present study, computer-generated imagery was displayed electronically on the IHADSS combiner to assess dynamic visual performance. The IHADSS has a manual focus adjustment (+3.5 to -6.0 D) to correct for spherical refractive error and accommodate posture, and additional adjustments to optimize image orientation and position of the combiner. The FPD (Honeywell Corp.) was an early prototype 640 x 480 active-matrix LCD (AMLCD) integrated into a head-mounted, see-through system (Fig. 2). This system, which includes a backlit AMLCD with green filter and combiner elements, is mounted to a lightweight headband with separate displays for each eye. Only the left channel was used in the present study to compare performance to the monocular IHADSS. The focus of the LCD system is fixed at infinity.

Imagery was software-generated from an IBM-compatible 486 computer operating at 66 MHz. An electronic interface supplied by Honeywell Corp. was used to present computer-generated imagery on the LCD, while the IHADSS interface and a COVID video adaptor were used to present imagery on the CRT. This adaptor also allowed simultaneous display of stimulus imagery on a remote video monitor for viewing and data collection by the experimenter. Prior to testing, luminance was measured directly from the center of each display at each software-generated intensity step (Minolta LS-110 photometer) and image contrast was computed. Electronic adjustments were made so that peak luminance (26.4 cd/m^2) and image contrast associated with software intensity steps used during testing were the same for the two displays. Specifically, the two displays were matched, as closely as possible, in terms of luminance and contrast. Electronic sizing adjustments were also made on the IHADSS such that the field of view was the same for each display (36 x 27 deg.)

Procedure. Dynamic visual performance was assessed with three tasks utilizing dynamic stimuli which, based on preliminary testing with conventional CRTs and LCDs, can reveal differences in temporal performance between displays. Flicker detection, target recognition *vs.* duration, and target recognition *vs.* velocity were assessed in five subjects tested on separate occasions with each display (two-way repeated measures design).

FIGURE 1 – The Integrated Helmet and Display Sighting System (IHADSS) used in the present study.

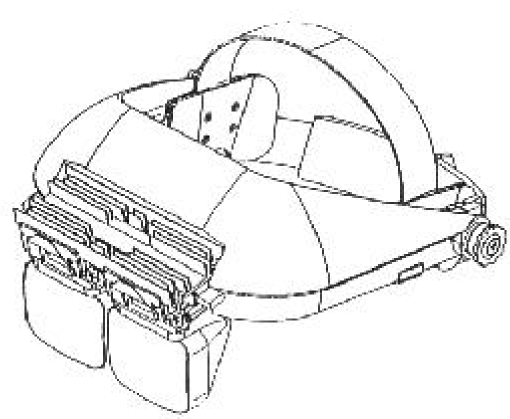

FIGURE 2 -- The head-mounted AMLCD obtained from Honeywell Corp. Only the left

Flicker detection was measured with a 4 x 2 array of eight patches of square-wave grating. Spatial frequency was 3.7 cycles/deg with 8 cycles per grating patch. This frequency was chosen because it was within the spatial-resolution capabilities of each display and approximated peak performance for human contrast sensitivity.[5] Each grating patch was numbered (1-8) and differed in contrast by approximately 0.1 log unit steps (1-highest contrast, 8-1owest contrast). On each trial, tile array of gratings was square-wave flickered at a different temporal frequency with values ranging from 0.5 to 16 Hz in 2x steps. The subject's task was to report the highest number grating *(i.e.,* lowest contrast) at which flicker could be detected. Subjects were also instructed to use half-steps if they felt their threshold

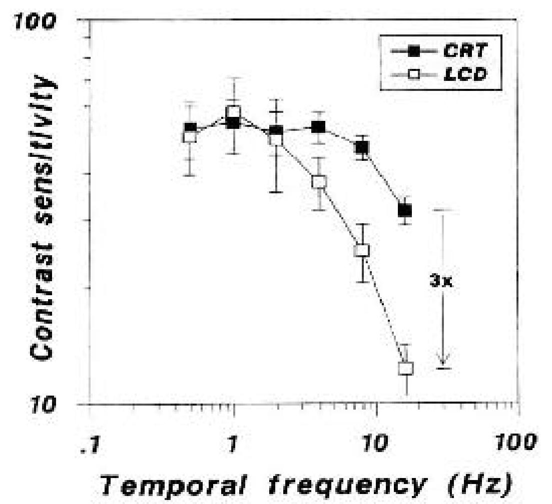

FIGURE 3 – Mean (+1 SE, n = 5 subjects) contrast sensitivity (1/contrast threshold) for detection of flicker in a grating stimulus (3.7 cycles/deg) is plotted against temporal frequency for the IHADSS (CRT) and LC displays. The array indicates a 3x difference in contrast sensitivity at the highest frequency tested (16)

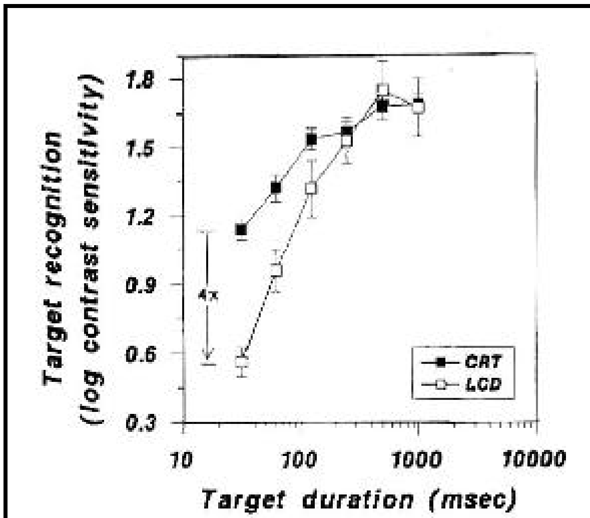

FIGURE 4 – Target recognition (mean ±1 SE log contrast sensitivity) is plotted against the duration of target exposure for the IHADSS (CRT) and LC displays. Targets were single letters (20/162 letter size) presented at the center of the display at various durations (31-1000 ms).

was between two numbered steps. Temporal frequencies were presented in random order and repeated three times at each frequency. The mean of the three values was computed as flicker-detection threshold for each frequency.

Target recognition was measured as a function of duration and velocity with a forced-choice letter-recognition task. For both experiments, letter size was 20/162 (0.68 deg), with each letter limb corresponding to a spatial frequency of 3.7 cycles/deg (the same spatial frequency used in the flicker-detection experiment). In the duration experiment, single letters appeared briefly, centered in a cross-hair at the center of the display. On each run, 15 letters were presented in succession. During the run, letter contrast decreased in approximately 0.1 log steps after each five letters. The subject's task was to read the letters aloud. The 15-letter run was then repeated, and credit was given for each letter read correctly during the two runs. The duration of letter exposure was varied randomly between runs with durations ranging from 31.3 to 1000 ms in 2x steps. A letter-recognition threshold was obtained from each subject for each duration. A similar procedure was used to measure letter recognition as a function of velocity. On each trial, a letter appeared at a fixed location 1.1 deg left of center and moved 2.2 deg left to right. The velocity of letter movement was varied between runs from 2.2 to 17.6 deg/s in 2x steps. Letter duration varied inversely with velocity. As in the duration experiment, 15 letters were presented in succession, with letter contrast decreasing in 0.1 log steps after each five successive letters. The 15-letter run was then repeated, and credit given for each letter read correctly during the two runs. A letter-recognition threshold was obtained from each subject at each velocity. As noted earlier, preliminary testing indicated that the stimulus durations and velocities used in this study were appropriate for revealing differences between displays.

The subjects were tested with each display in separate sessions (LCD first, IHADSS second, due to system availability). There was a nearly 2-month hiatus between test sessions with each system, making it unlikely that transfer or learning effects occurred. Testing was conducted in a dark room, and the external portion of the see-through optics on each display were occluded to prevent stray light from reducing image contrast. Prior to each experiment, the subject was seated comfortably, and a member of the experimental team ensured that the device was properly fitted. Testing was performed monocularly on the subject's left eye while the right eye was occluded.

3 Results

Figure 3 shows mean (+-1 SE) contrast sensitivity (1/contrast threshold) plotted against flicker frequency. As shown previously,[5] sensitivity is maximum at low-to-moderate frequencies, but declines with increasing flicker frequency. Two-way ANOVA with repeated measures across frequency and display revealed a significant main effect of frequency [F(5,20) = 24.76, p

< 0.001], and a significant interaction [$F(5,20) = 10.22$, $p < 0.01$]. Posthoc comparisons (Tukey HSD test) showed significant differences between displays at the two highest frequencies (8 and 16 Hz; $p < 0.01$). As indicated in Fig. 3, contrast sensitivity was 3x lower with the LCD at the highest flicker frequency. Figure 4 shows target recognition (mean +1 SE log contrast sensitivity) plotted against target duration for the two displays. As expected, performance decreased with decreasing target duration, but the decline was more rapid with the LCD. Two-way ANOVA with repeated measures across duration and display revealed a significant effect of duration [$F(5,20) = 134.87$, $p < 0.001$], and a significant interaction [$F(5,20)$ - 26.59, $p < 0.001$]. Posthoc comparisons (Tukey HSD test) again showed significant differences between displays at the three shortest durations (30-125 ms, $p < 0.01$). As shown in Fig. 4, contrast sensitivity was 4x lower with the LCD at the shortest duration of target presentation.

Figure 5 shows target recognition (mean +1 SE log contrast sensitivity) plotted against target velocity for each display. As shown in previous studies of dynamic visual acuity,[6-8] performance decreased with increasing target velocity, but the decrease clearly was more rapid with the LCD. Two-way ANOVA with repeated measures across velocity and display revealed a significant effect of velocity [$F(3,12)= 159.46$, $p < 0.001$], and a significant interaction [$F(3,12) = 23.18$, $p < 0.001$]. Posthoc comparisons (Tukey HSD test) revealed significant differences between displays at the three highest velocities (4.4-17.6 deg/s, $p < 0.001$). As shown in Fig. 5, contrast sensitivity was 5x lower with the LCD at the highest velocity of target presentation.

4 Discussion

This study demonstrates differences in performance between the tested CRT and LC displays at high rates of image presentation. Since the stimuli presented on each display were matched in terms of peak luminance and spatial extent, and because the same methodology and human subjects were used for each display, it is unlikely that these factors contributed to the differences observed. It is also unlikely that differences in the green color of the LCD and CRT affected the results. Both displays were isochromatic *(i.e.,* shades of green), with stimuli modulated in luminance rather than color contrast. Since testing was conducted with the LCD prior to the CRT, it might be argued that enhanced performance with the CRT was due to a learning effect. However, nearly 2 months intervened between test sessions with each device, reducing the likelihood that learning played a significant role. Moreover, if the enhancement in performance with the CRT was due to learning, then this effect would not necessarily be limited to high rates of image presentation.

It is more likely that the results reflect differences between contrast response times of each display. Liquid crystal cells have relatively slow response times (full-on to full-off in 100-300 ms).[3] The slower temporal response causes contrasts produced under dynamic conditions to be lower than values expected from static photometric measures. Apparently, this is a limiting factor even in AMLCDs in which a thin-film-transistor (TFT) array controls individual pixel elements. In contrast, CRT phosphors have much more rapid response times (microseconds to milliseconds), which afford better temporal resolution.[1]

The present results are important for designers of helmet-mounted displays contemplating the use of LCDs. If a system like the one in this study were fielded, one might expect reduced visibility (relative to a CRT) for rapidly moving image content. It is emphasized, however, that the present report compares a proven CRT system to an LCD under development, with modifications and improvements forthcoming. The methodology described here and further research and testing Will provide a rational basis for selection and development of optimal flat-panel technology for use in military and civilian environments.

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