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Visual search performance on LCD and CRT displays: an experimental comparison

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20.3: Visual Search Performance on LCD and CRT Displays: An Experimental Comparison

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Abstract

We examined visual search performance using 52-cm liquid-crystal (LCD) and cathode-ray tube (CRT) displays. Twenty-four subjects searched for navy tactical display symbols on a map background. When display clutter was low (few symbols), there was a CRT advantage for off-axis viewing, but this advantage disappeared as the number of symbols increased.

1. Objective and Background

This paper describes an experiment that examines the relative effectiveness of two display technologies, a liquid-crystal display (LCD) currently under development at Computing Devices Canada (CDC), and a conventional cathode-ray tube (CRT) of similar resolution and size. The study compared the displays not in terms of display optics but rather in terms of human performance. Work in the Human-Computer Interaction Group at DCIEM has focused on the use of displays by the Canadian Navy. Within the Navy, there is interest in the use of LCD panels on ship because of their lower power consumption and weight, lowered susceptibility to electromagnetic interference, and smaller footprint.

Although some studies comparing LCD and CRT technologies have used subjective ratings as a measure of display quality [6], relatively little attention has been given to more objective task performance measures, such as accuracy and response time. We argue that a visual search task [3,7,8] should serve as an appropriate benchmark for examining human performance using different display types. Visual search is a necessary component task for many naval shipboard operations [3]. In visual search, an observer looks for a particular target symbol among many distractors on a display, and must indicate if the target is present or not. Increased error or response time in visual search with a display unit implies that the search process is less efficient with that display.

In addition to display type, we manipulated viewing angle and symbol size. A well-known problem for LCD technology is that off-axis viewing can be problematic, both in terms of reduced luminance and colour distortion [5]. This is a special problem for display viewing in the naval operations room, because it is common for multiple individuals to examine the same display, some of whom are standing left or right of the display screen. Hence, it is important to determine whether visual search is degraded more by off-axis viewing of LCD than CRT displays.

Conventional Naval tactical displays use the NTDS (Navy Tactical Display) symbology. Typically these symbols are portrayed at approximately 6 mm^2, which corresponds to approximately 41 minutes of arc at a 50 cm viewing distance. Differences between symbols in the set can represent the change of value of about 10-20 pixels. Detecting differences between symbols may be compromised still further when a wide field of view needs to be portrayed. There are two solutions: 1) Make the symbols smaller, or 2) Keep the symbols the same size as with small fields-of-view. The first solution may make the symbols more difficult to discriminate (since fewer pixels can be used to render the symbol). The second solution may produce clutter and require the discrimination of overlapping symbols. However, the high contrast ratio of the LCD [4] may make the first solution effective for visual search with small symbols, thereby allowing the observer to have the wide field of view and discriminate detail.

Thus, independent variables for the experiment were 1) display type (LCD vs. CRT); 2) viewing angle, and 3) symbol size (large vs small) The number of distractor symbols shown on a trial (set size) was also manipulated, as was the presence versus absence of the target symbol on a particular trial. The primary dependent variables were accuracy and response time. Subjective measures were also collected.

2. Method

2.1 Subjects

There were 24 subjects, all CDC employees ranging in age from 20-61 years. Subjects had normal or corrected-to-normal vision.

2.2 Apparatus and stimuli

The two display types were a prototype flat-panel active-matrix in-plane switch LCD in development by CDC and a Sun Microsystems GDM-20E20 CRT Both displays were approximately 52 cm (20.5 in) measured diagonally, and had 1280 x 1024 pixel resolution at .31 mm dot pitch. The displays were controlled by a Sun workstation. A chin rest was used to keep the subject's head stationary during the experiment. The viewing distance was kept constant at 50 cm for both display types and both viewing angles.

The symbols shown on each trial were members of a set of 9 NTDS symbols shown in Figure 1 [3]. All symbols were white and stationary. Symbols were shown on a map background. Colours (as designated by the X-Window system) for the map/background were "gray25" (a dark gray approximately 25% of the way between black and white) for land and "dark slate blue" for water. For both display types, the white symbols had a luminance level of 72 cd/m^2, the blue background had a luminance level of 2 2 cd/m^2, and the gray background had levels too low to be reliably measured.

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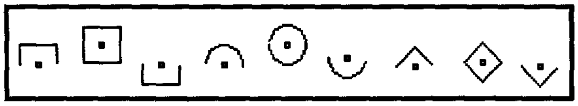

Figure 1. Set of 9 NTDS Symbols used in Experiment.

2.3 Design

The experiment had a 2 (Display Type) x 2 (Viewing Angle) x 3 (Set Size) x 2 (Symbol Size) x 2 (Target Presence) between/within design, with the first two factors manipulated between subjects and the last three manipulated within subjects. The two display types were LCD and CRT. The two viewing angles were 0 and 60 degrees of azimuth (i.e., the display was rotated about its vertical axis 60 degrees so that the screen was angled relative to the subject's head in the chin rest). The three set sizes (i.e., total number of symbols shown during a trial) were $S = 10$, 30, and 50 The two symbol sizes were 19 x 19 pixels (large) and 13 x 13 pixels (small), approximately corresponding to 6 and 4.24 mm^2 (for the square symbol in Figure 1). The smaller stimulus size was therefore half the area of the larger.

For each of the 2 (Symbol Size) x 3 (Set Size) = 6 conditions (blocks), there were 36 trials. Within a block, each of the 9 NTDS symbols was shown as a target twice, producing 18 *target-present* trials. On the other 18 *target-absent* trials, no target was shown. On target-absent trials, there were S distractor symbols, and on target-present trials $S - 1$. The distractor symbols were sampled with replacement from the set of 9 symbols excluding the target symbol. Symbols were placed in random display positions on each trial, with the constraint that they did not overlap. The order of the 36 trials within a block was randomly determined. The order of the 6 blocks was counterbalanced across subjects using a Latin square.

Subjects pressed the '1' key on the numeric keypad (labelled with a 'P') for "TARGET PRESENT" and the '2' key on the numeric keypad (labelled with an 'A') for "TARGET ABSENT". The subject's response and the response time (to the nearest millisecond) were recorded.

2.4 Procedure

Each subject was randomly assigned to particular levels of the between-subjects conditions, and a particular order of the 6 conditions (blocks) defined by the factorial combination of Set Size and Symbol Size. Subjects filled out a consent form, and then read a set of instructions. In the instructions, subjects were told that they would first see a target symbol, and that when they had familiarized themselves with the target, they should press a key to see a display showing a set of randomly arranged symbols. They were instructed that their task was to determine if the target symbol was in the set.

Subjects then performed 6 practice trials, one trial representing each of the 6 blocks. Then they proceeded through the experimental trials On each trial, the target symbol was shown, the subject pressed a key when ready, and the symbol set was displayed. This display was shown until the subject responded "present" or "absent", whereupon the next trial commenced. It took approximately 45 minutes to run a subject through the procedure. After completion, the subject received a written debriefing form, filled out a questionnaire and discussed the experiment with the experimenter.

The questionnaire contained three Likert (1-7) rating scale items: Clarity ("How clearly could you see the symbols?", 1-very clearly—7 not clearly at all); Confidence ("How certain were you that you were making accurate judgments?", 1-very certain—7 not certain at all); and Display Quality ("In general, how would you evaluate display quality?", 1-excellent—7 poor).

3. Results

3.1 Accuracy

A mean accuracy score was computed for each subject in each of the experimental conditions. To correct for observed heterogeneity of variance, an arcsine transformation was applied to the scores [1] The transformed scores were then submitted to a between/within analysis of variance (ANOVA) with Display Type and Viewing Angle treated as between-subjects variables and Set Size, Symbol Size, and Target Presence treated as within-subjects variables. An interaction between Display Type, Viewing Angle, Set Size, and Target Presence was found, $F(2,40) = 5.60$, $p < .01$, shown in Figure 2. When the target was present, accuracy decreased with set size, but when the target was absent, set size had little effect on accuracy. In addition, for the CRT, increasing the number of symbols decreased target-present accuracy more severely for off-axis than on-axis viewing, but for the LCD, the reverse was true. In particular, when the target was present and the set size was small (10), accuracy was greater for the CRT than the LCD for off-axis viewing (Newman-Keuls post hoc test, $p < .05$). However, for on-axis viewing, there was a trend in the reverse direction (mean accuracy greater for the LCD than the CRT), although it did not reach conventional significance levels.

The analysis also revealed that accuracy was generally higher for target absent than for target present trials, $F(1,20) = 113.08$, $p < .0001$ There was an interaction between Symbol Size and Viewing Angle, such that large symbols were more accurately detected than small with off-axis viewing, but there was no difference between large and small symbols for on-axis viewing, $F(1,20) = 5.02$, $p < .05$.

3.2 Signal detection analysis

To establish whether the changes in accuracy were a result of a change in perceptual sensitivity or rather a change in response bias (i.e., inclination to say that a target was present vs. absent), a signal detection analysis [2] was conducted. Measures of sensitivity (d') and response bias (β) were computed for each condition. Each measure was submitted to a between/within ANOVA. Sensitivity decreased with Set Size, $F(2,40) = 16.35$, $p < .0001$, but there was no interaction with Display Type or Viewing Angle, all $ps > .30$. With small symbols, sensitivity was greater for on-axis than off-axis viewing, but Viewing Angle had no effect on sensitivity with large symbols, $F(1,20) = 5.25$, $p < .05$.

The bias analysis showed that β was positive ("conservative"), indicating that subjects were generally biased against saying a target was present. This bias increased with Set Size, $F(2,40) = 15.97$, $p < .0001$, indicating that subjects became even more conservative with larger sets. In addition, a three-way interaction between Display Type, Set Size, and Viewing Angle approached conventional significance levels, $F(2,40) = 2.94$, $p = .064$. As Figure 4 shows, increasing the number of symbols increased β more severely for off-axis than on-axis viewing for the CRT, but for the LCD, the reverse was true. An increase in conservative bias would result in lower accuracy in target present trials. Note that the increases in β just described therefore underlie the decreases in accuracy depicted in Figure 2

3.3 Response time

A mean response time (RT) for correct trials was computed for each subject in each experimental condition. A logarithmic transformation was applied to stabilize observed heterogeneity of variance [1] The transformed data were submitted to a between/within ANOVA as above RTs increased with Set Size, $F(2,40) = 389.50$, $p < .0001$, but at a faster rate for target-absent than target-present trials, $F(2,40) = 41.61$, $p < .0001$ (see Figure 4). The search rate (slope of the target absent function) was about 200 ms per symbol.

For the CRT, RTs were longer for off-axis than on-axis viewing; there was no effect of viewing angle for the LCD display, $F(1,20) = 6.12$, $p < .05$. RTs were shorter for large than small symbols, $F(1,20) = 63.57$, $p < .0001$.

3.4 Subjective measures

Three subjective measures were collected using a Likert rating scale. Clarity, Confidence, and Display Quality. In general, the pattern of means showed better ratings for CRT than LCD for on axis viewing, and the reverse (better ratings for LCD than CRT) for off-axis viewing. However, this pattern was strongest and reached conventional significance levels only for Display Quality, $F(1,20) = 4.71$, $p < .05$

4. Impact

The advantages for particular display types depended upon levels of other factors such as viewing angle and set size. For the CRT, increasing the number of symbols decreased target-present accuracy more severely for off-axis than on-axis viewing, but for the LCD, the reverse was true. The signal detection results showed, however, that the accuracy results were driven by response bias, and not sensitivity That is, the subjects' ability to detect the target was not affected by display type, but their inclination to say whether or not a target was presented was affected. There was a general conservative bias towards saying "target absent"; this increased more quickly with set size in off-axis CRT and on-axis LCD conditions, conditions also rated lower on display quality.

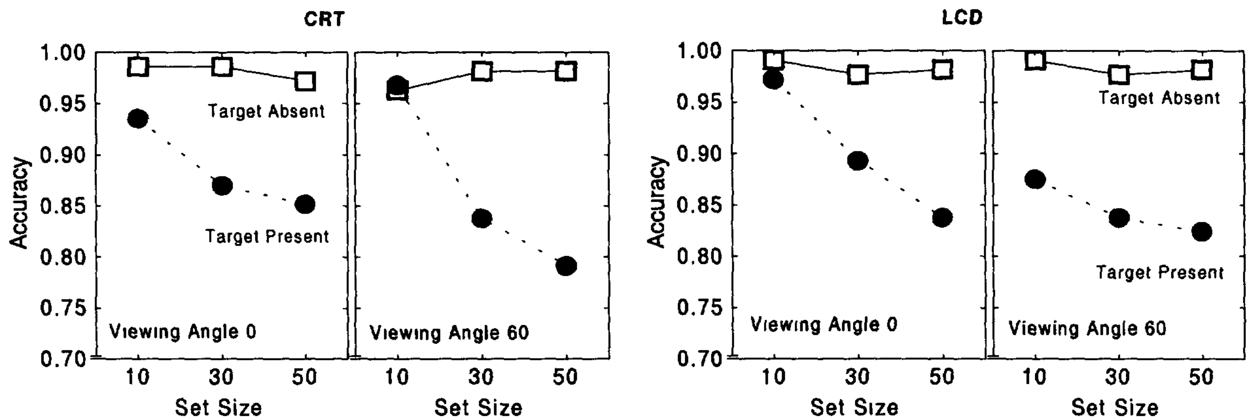

Figure 2. Accuracy as a function of Display Type, Viewing Angle, Set Size, and Target Presence.

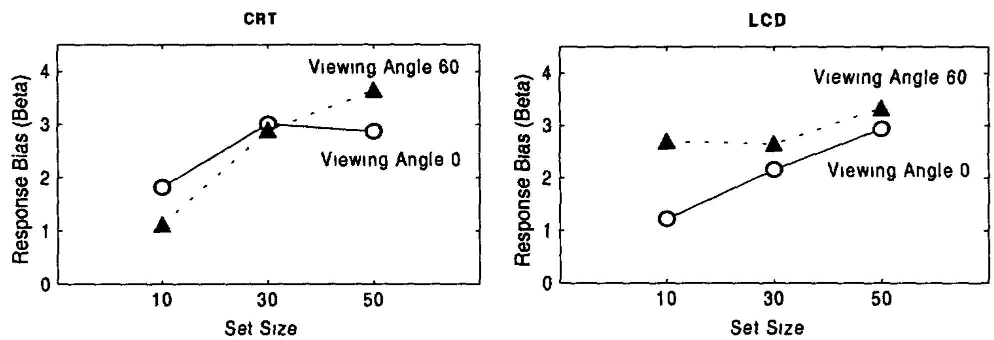

Figure 3. Response Bias (β) as a function of Display Type, Viewing Angle, and Set Size.

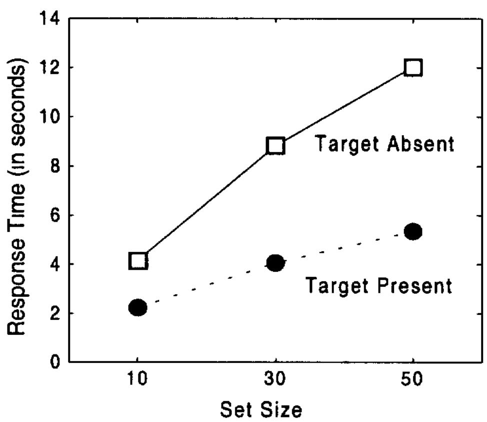

Figure 4. Response Time as a function of Set Size and Target Presence.

This is ironic when one considers that off-axis CRT and on-axis LCD conditions produced some of the greatest target present accuracies (and lowest bias scores). When set size was small and display clutter therefore low, off-axis CRT was better than off-axis LCD, and there was a trend toward on-axis LCD being better than on-axis CRT. Why therefore, should those conditions producing higher accuracy receive lower subjective ratings? One reason is that their greater effectiveness was limited to the small set size condition, and that their effectiveness fell off more rapidly when set size increased than did their counterparts. That is, off-axis CRT and on-axis LCD were more adversely affected when display clutter was greater, and therefore could be seen as less "reliable". In contrast, on-axis CRT and off-axis LCD produced more consistent accuracies across the range of set sizes, and therefore there would be less perceived need to adjust response bias.

We predicted that visual search should have been degraded more by off-axis viewing for the LCD than the CRT displays. The only evidence of this occurring was with small set sizes in the target present situation. The decreased accuracy, was, as noted above, due to a greater bias towards saying "target absent" with off-axis LCDs versus CRTs. It appears that the CRT holds its advantage for off-axis viewing (presumably due to its greater luminance off-axis relative to the LCD) only when clutter is low. When clutter is high, there is little to distinguish the two display types for off-axis viewing.

We also expected that the high contrast ratio of the LCD should have made it more effective for visual search with small symbols. There was no evidence in accord with this prediction.

Response times were longer for off-axis than on-axis viewing for the CRT; but there was no effect of viewing angle for the LCD display. This result is in keeping with the target-present accuracy results for large set sizes—whereas there was a trend toward mean accuracies being lower for off-axis than on-axis CRT, there was little difference in accuracy between off-axis and on-axis LCD. The results also showed that response times increased with set size at a faster rate for target absent than target present trials; indeed, the rate of increase for target absent trials is about twice that for target present trials, consistent with a (at least partial) serial search strategy [7,8]. This implies that the above results pertain when observers are inspecting symbols in serial fashion; whether the relative advantages for one display type over another seen here are replicated in parallel, "pop-out" situations remains untested.

In addition to the results showing differences between display types, there were several advantages found for larger symbols. Larger symbols were in general faster to detect, and reduced error with off-axis viewing. This was due to a change in sensitivity, and not response bias: viewing angle had no effect on sensitivity with larger symbols, but off-axis viewing decreased sensitivity with smaller symbols. These findings support the use of relatively large symbol sizes even in cluttered displays – at least under conditions where symbols do not overlap.

In summary, we note that the visual search tasks appears to be a fruitful and informative method for examining human performance using different display technologies.

5. Acknowledgments

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6. References

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