The Effect of Target Color and Contrast on Movement Times in Aimed Movement Tasks

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Today's use of various devices and software requires pointing, clicking or touching within a variety of graphic user interfaces. Understanding the effect of the potential variety of interface elements on these interactions or aimed movements will assist in optimizing performance within these interfaces. This study addresses the potential effect of color and contrast of targets on performance in aimed movement tasks through a pointing and clicking task on the computer. Target size, color, contrast, and movement direction were manipulated, measuring any effect on movement time and errors. Size had an effect on movement time, as predicted by Fitts' law, with a decrease in performance as size decreased. Color had no significant effect on movement time or errors. Target contrast interacted with size in both movement time and error analysis; as size decreased, high contrast targets were hit faster and produced more errors than low contrast targets. Direction had an effect on movement time, with faster movements to the left.

INTRODUCTION

Since the development of the graphic user interface, human computer interaction has become much more than simple text entries. Aimed movements, or pointing and clicking on icons, menu items, tabs and command buttons are all common methods of interacting with computer software. In addition, the emergence of the internet has introduced a variety of new interactive interfaces. Any text, graphic, or segment of either displayed on a web page can be used as a "hot spot," or an interactive element, intended to be clicked on.

Beyond computer use, aimed movement tasks are encountered throughout the day, requiring one to interact with a variety of graphic user interfaces containing elements of different shapes, sizes and colors. From using a telephone to a touch screen navigational device, aimed movement tasks are ubiquitous. Some of these movement tasks are critical, requiring fast and accurate responses, such as controls on medical equipment, emergency shut-down buttons or entering a security code in an alarm system. Other tasks may simply require accuracy, such as using an automated teller machine, adjusting computer system settings, or using a remote control. No matter what the task is, performance in these human-machine interactions is important.

Optimizing performance within interfaces has taken into consideration several factors, particularly the color, size, and position of elements. Understanding how these factors interact with the human cognitive, perceptual and motor control systems is essential for optimizing performance.

The use of color in graphic user interfaces is commonplace today. In addition to esthetic properties, effective color use can provide many benefits to user interfaces. Varying the color or contrast of interface elements has been shown to be effective in highlighting objects and can assist in discrimination between objects, improving performance in search and identification tasks (Brown, 1991; Van Orden, Divita, and Shim, 1993; Bauer, Jolicoeur & Cowan, 1996). In addition, color can assist in recognition or indicating purpose of interface elements (Galitz, 2002).

The color of an object though, can affect perception of the object, potentially affecting our interaction with that object. Warmer colored and less saturated lighter colored objects have been found to appear larger than their counterparts, cooler colored and more saturated colored objects (Gundlach & Macoubrey, 1931; Wallis, 1935; Tedford, Bergquist & Flynn 1977). This object property of color was in fact found to affect the grasping phase in prehension movements, where red objects were estimated to be larger than green objects (Gentillucci, et al., 2001). Likewise, color and contrast of targets may affect their perceived size, interfering with the accuracy of the refined movements in the current control phase of aimed movements.

Visual fixation on targets has a direct effect in performance in aimed movements, with increased fixation improving performance and eliminating fixation decreasing performance (Jeannerod, 1990). A potential deficiency in the visual system to focus and fixate on small blue objects (Murch, 1984), may impede one's ability to focus or fixate on small blue or light blue targets, possibly decreasing performance in aimed movements towards these targets.

Touch screen interfaces, common in kiosks, ATMs, or navigational systems, are commonly accessed in various lighting conditions, resulting in varying levels of contrast in the display. As low levels of contrast can potentially affect reading performance, particularly with smaller characters (Legge, Rubin and Luebker, 1987), low levels of contrast within these displays may also affect one's ability to focus on and ultimately interact with smaller elements.

One of the wider known and accepted principles involving interface performance is Fitts' law (Fitts, 1954), which deals with size and position of targets within aimed movement tasks. Fitts' research not only determined that the size of and distance to targets directly affect movement times towards the target, but also established a commonly accepted methodology of experimentation and evaluation of performance in these tasks.

The purpose of this experiment is to determine the effect of color of target, and contrast between target and background on movement times in aimed movement tasks. The methodology established by Fitts' research will be the basis for this experiment.

The hypotheses proposed are: (a) movement times will differ while aiming for targets of different colors; (b) movement times will increase as the contrast between target and background decreases; and (c) an interaction between target size and target contrast will occur, with a greater increase in movement times towards smaller low contrast targets than towards larger low contrast targets.

METHOD

To determine the potential effect of color and contrast on performance in aimed movement tasks, a pointing and clicking task on a computer was developed for this experiment. Within-subject independent variables were target size, color and contrast, and direction of movement. Dependent variables measured were movement time (MT) and error rates (ER).

Four square target sizes were used, 8, 16, 32, and 64 pixels, with approximate screen dimensions of 2, 4, 8, and 16 mm. These sizes were based on and extrapolated from the recommended icon sizes of 16 x 16 or 32 x 32 pixels (Galitz, 2002), and are the same target widths used by MacKenzie (1991). With a viewing distance of 50 cm, the visual angles of the targets were approximately .23°, .46°, .92° and 1.84°, so all but the largest sized target fall within the viewing area of the fovea.

Targets were composed of four colors, black, red, green and blue, and were presented on a white background. Each color was set at two levels of contrast, high (equivalent in luminance to 90% black) and low (equivalent in luminance to 10% black).

Two directions of movement were used, diagonally to the upper right, and diagonally to the upper left (approximately 50° diagonals). One distance of 552 pixels was used, an approximate screen distance of 17 mm. To decrease rehearsal effects, ten distracter trials of varying distance and position were randomly introduced into each session. These trials were excluded from data analysis.

Participants

Thirty six SJSU students (28 women and 8 men) participated in this experiment. All were between the ages of 19 and 40, were right handed and had normal vision. Desktop computer experience ranged from 5 to 16 years.

Apparatus

This experiment was conducted on a desktop computer with a 19 inch (48 cm) LCD flat panel display. System display settings were at 32 bit color with a resolution of 1280 x 1024. The monitor settings (color, contrast, brightness) were all set to default levels. Participants sat at a table, approximately 50 cm from the monitor.

A Java applet was created for this experiment, running within Windows Internet Explorer. The display consisted of three elements. The first, the *starting box,* was a 32 x 32 pixel outline of a square, consistently located at the lower center of the display. The second element was the *target*, which varied in color, contrast, size and position. At the beginning of each trial, a 64 x 64 pixel outline of a square would appear for one second as a *cue*, indicating the position of the target for that trial (see Figure 1).

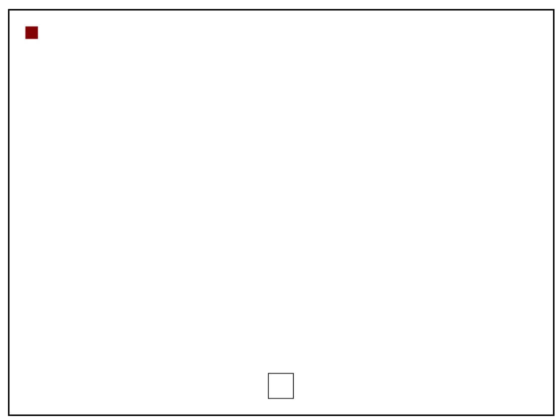

Figure 1. Screen shot of the application, showing the starting box and a target.

Procedure

The task described to the participants was to click on the starting box, then move the mouse and click on the target as fast as possible while maintaining accuracy. A trial was completed when the participant clicked on the target, at which point the target disappeared and a cue appeared, indicating the beginning of the next trial and the position of the next target. A warm-up consisting of 10 to 12 trials was provided to each participant. Following the warm-up, each participant conducted 5 sessions of 74 randomly presented trials (64 experimental and 10 distracter trials).

RESULTS

Data Adjustment

To determine any rehearsal effect, a one-way analysis of variance (ANOVA) and a Tukey Pairwise Comparison test at 95% CI were run on the factor repetition. Combined results indicated a rehearsal effect between repetitions one and all others, which was reduced by eliminating repetition one from the data set.

Outliers were found in approximately 0.9% of the data. These were identified at each level of size, color and contrast, and were adjusted to the means of those levels of factors for the respective participant.

Errors were misses when attempting to hit the target. If multiple misses occurred during a trial, error rates accumulated. Four participants were found to have errors in more than 15% of their trials and accounted for more than 5% of overall errors. These four participants' data was removed. The remaining 892 errors occurred in 758 (9.26%) of the trials. The effect of these errors on movement time was avoided by adjusting the time on those trials to the means of those levels of factors for the respective participant.

The final adjusted data was composed of 32 participants, 4 repetitions and 64 levels of factors and was used in all subsequent analysis.

Movement Time

The dependent variable movement time was analyzed using a 32 (participants) x 4 (sizes) x 4 (colors) x 2 (contrasts) x 2 (directions) within subject ANOVA

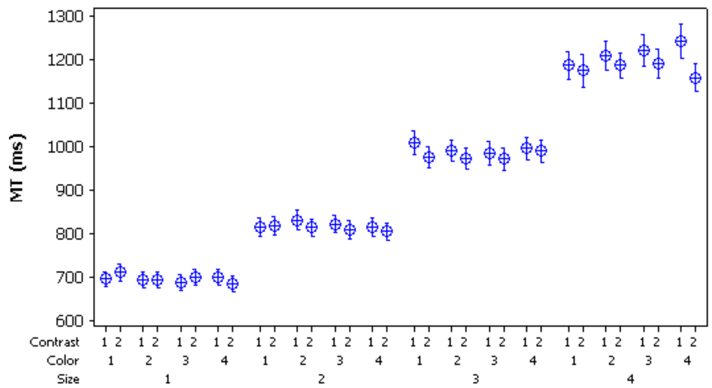

Figure 2. Mean MT vs. Size, Color and Contrast. Size 1=largest, 4=smallest. Color 1= black, 2=red, 3=green, 4=blue. Contrast 1=low, 2=high.

at 95% CI, collapsed across repetition. Summary data is displayed in Table 1 and Figure 2.

As expected, a significant main effect of size was found, $F(3, 6144) = 747.13$, $p < .001$, with faster movements towards larger targets. The main effect of color was not found to be significant $F(3, 6144) = .01$, $p = .999$.

The main effect of contrast was significant $F(3, 6144) = 12.31$, $p = .001$. Movements towards high contrast targets were faster, with a difference in mean MT of 14.92 ms or 1.6%. A size x contrast interaction was also significant $F(3, 6144) = 4.53$, $p = .005$. The difference between low and high contrast targets (contrast 1 and 2) in MT increased from 8.9 ms to 17.7 ms to 36.8 ms for the three smaller sized targets (see Figure 3). Simple main effects show contrast only had a significant effect on MT at the smallest size target (size 4), $F(1, 2046) = 9.01$, $p = .003$.

Table 1: Descriptive Statistics - Adjusted Data

	Color								Direction		
	Black		Red		Green		Blue				
Size	Low	High	Low	High	Low	High	Low	High	Left	Right	ALL
1	695.6	711.0	692.7	694.8	687.9	700.2	700.5	685.7	684.8	707.3	696.1
	142.3	159.2	147.1	149.3	138.2	140.8	153.1	146.4	146.0	147.4	147.1
2	815.2	818.7	831.4	814.0	822.5	809.7	814.1	805.4	802.9	829.8	816.4
	169.7	168.8	177.1	162.3	166.2	172.0	170.4	157.8	165.5	169.5	168.0
3	1008.6	975.6	992.0	972.5	984.4	972.1	996.0	214.4	974.7	998.1	986.4
	214.5	202.1	200.6	190.4	213.7	205.4	211.4	989.8	202.5	210.3	206.7
4	1186.8	1175.8	1209.8	1186.8	1220.4	1191.7	1242.4	1157.9	1181.4	1211.5	1196.5
	251.2	307.5	266.9	238.2	299.0	268.7	317.6	260.5	277.7	277.9	278.1
All	926.6	920.2	931.5	917.0	928.8	918.4	938.3	909.7	911.0	936.7	923.8
	273.0	279.0	279.4	263.3	291.1	274.1	302.2	268.8	277.0	280.7	279.1

Note. Cells contain mean movement time (ms) and standard deviation.

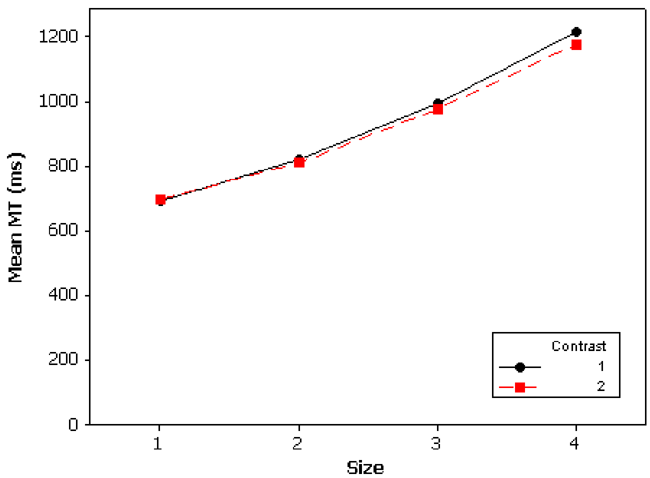

Figure 3. Mean MT vs. Size and Contrast. Contrast 1= low; contrast 2 = high.

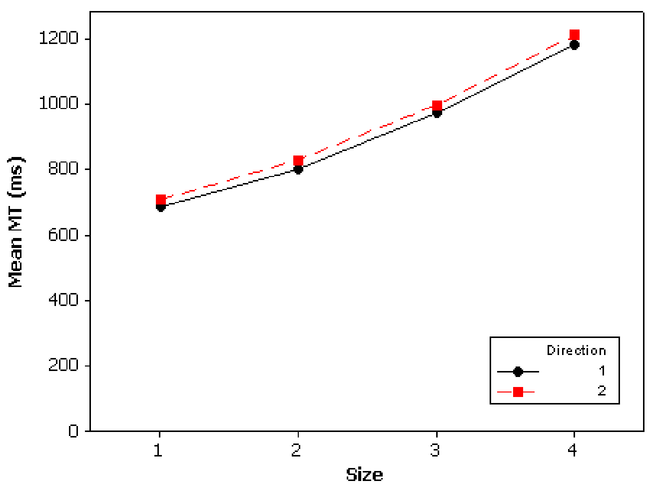

Figure 4. Mean MT vs. Size and Direction. Direction 1 = left; direction 2 = right.

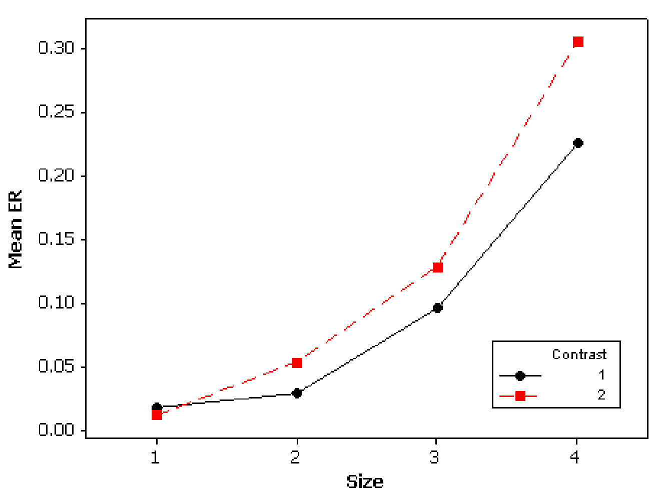

Figure 5. Mean ER vs. Size and Contrast. Contrast 1= low; contrast 2 = high.

The main effect of direction was also found to be significant, $F(1, 6144) = 11.10$, $p = .002$. Movements to the left (direction 1) are consistently faster than movements to the right (direction 2) (see Figure 4). The difference in mean MT was 25.7 ms, or 2.7%.

Errors

Error analysis found 9.25% of trials contained errors. Over 10% of attempts to hit the third smallest target (16 x 16 pixels), and over 20% of attempts to hit the smallest target (8 x 8 pixels) resulted in errors.

Errors were analyzed using the same ANOVA model as movement time. The two way interaction of size x contrast was significant, $F(3, 6144) = 5.45$, $p = .002$, with more errors in the smaller high contrast targets (contrast 2) than the smaller low contrast targets (contrast 1) (see Figure 5). Simple main effects show contrast had a significant effect at all but the largest size targets: size 2, $F(1, 2046) = 7.51$, $p = .006$ (45% difference); size 3, $F(1, 2046) = 4.34$, $p = .037$ (25% difference); and size 4, $F(1, 2046) = 10.01$, $p = .002$ (26% difference).

DISCUSSION

Aimed movement tasks are executed throughout the day using a number of devices including machinery, handheld devices and computers. Along with the variety of devices comes a variety of interfaces one must interact with. Using a computer alone, the variety of graphic user interfaces encountered requires one to point and click on elements or targets of many different shapes, sizes, and colors.

The purpose of this study was to determine if some of these varieties of interactive elements encountered have any effect on performance within a graphic user interface. More precisely, how does the color and contrast of targets affect movement times in aimed movement tasks?

It was hypothesized that using a computer mouse to click on targets of different colors would result in different movement times, and that clicking on targets with a lower level of contrast would result in slower movement times. In addition, an increased effect of contrast was expected as target size was reduced.

The expected effect of target color did not occur. There was no significant difference in movement times while aiming towards targets of different colors. Despite the low level of blue sensitive cones in the retina and their absence in the fovea, blue targets did not take any longer to hit, nor did they result in more errors than the other colored targets. This lack of effect may be due to the visual system's ability to compensation for the uneven distribution of cones in the retina through a potential chromatic interpolation system in the brain (Shevell, 2003).

In this experiment, all targets were displayed with some level of contrast. To more accurately determine a potential effect of color, the factor of contrast should be eliminated. Displaying the targets on an equal luminance background will remove the contrast, isolating the factor of color, allowing any effect to be revealed.

As predicted, contrast between the target and background did have an effect on movement time, with slower times for low contrast targets. This effect interacted with size, and was statistically significant at the smallest size target with a difference in mean movement times of 36.8 ms or 3.1%. These findings suggest that when speed is a concern and targets are small (below 16 x 16 pixels), higher contrast targets are recommended.

Two directions of movements were used for this experiment, diagonally to the upper left and the upper right. Direction of movement had a significant effect on MT, with movements to the upper left consistently faster than movements to the upper right, across all sizes and colors. This observation is supported within biomechanical research which found short adductive limb movements faster than short abductive movements (Morgan et al., 1994; Jeannerod, 1990). Considering efficiency of performance, this supports the convention of positioning menu items to the left of displays, for the majority of the (right handed) population.

Errors occurred in 9.25% of the trials. Even within the smaller of the two recommended icon sizes, 16 x 16 pixels (Galitz, 2002), over 10% of trials resulted in errors. From this finding, it is recommended that in tasks where accuracy is important, target sizes should be 32 x 32 pixels or larger, which should result in accuracy rates greater than 95%.

On all but the largest sized target, fewer errors occurred when aiming for the low contrast targets than the high contrast targets. These results suggest that in cases where accuracy is important and targets are 32 x 32 pixels or smaller, lower contrast targets are recommended.

Significant to note is that a speed-accuracy tradeoff appears to have occurred within the context of contrast. High contrast targets produced both faster movement times and more errors, predominantly in the smaller size targets. Two possible theories to explain this phenomenon are that the more visible high contrast targets may have affected participant's confidence in their ability to hit the target, increasing their speed and decreasing their accuracy. Alternatively, focusing on the more difficult to see lower contrast targets, may result in longer and more concentrated eye fixation periods, which may increase closed loop feedback, allowing increased precision in hitting.

Additional research is recommended to confirm these results and the proposed theories to account for these findings. Does the intrinsic target property of contrast affect individual's perceived ease of use or the visual system's fixation periods, and do those fixation periods allow for more accurate movements?

In summary, the target property of contrast appears to have an effect on both speed and accuracy in hitting a target, while movement direction appears to have an effect on movement time. Further studies could more accurately isolate and determine any possible effect of target color within aimed movement tasks. Though some levels of effects may not have practical significance, supplied recommendations could be applied to specific tasks.

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