San Jose State University
SJSU ScholarWorks

Master's Theses | Master's Theses and Graduate Research

2000

The effect of highlighting on the identification process during visual search

Stephen Tse
San Jose State University

THE EFFECT OF HIGHLIGHTING ON THE IDENTIFICATION PROCESS DURING VISUAL SEARCH

A Thesis

Presented to

the Faculty of the Department of Human Factors/Ergonomics

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Stephen Tse

May, 2000

UMI Number: 1399829

Bell & Howell Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

APPROVED FOR THE DEPARTMENT OF
HUMAN FACTORS/ERGONOMICS

Kevin Jordan, Ph.D.
Professor of Psychology, San Jose State University

Walter W. Johnson, Ph.D.
Research Psychologist, NASA Ames Research Center

Kevin M. Corker, Ph.D.
Associate Processor of CISE, San Jose State University

APPROVED FOR THE UNIVERSITY

ABSTRACT

THE EFFECT OF HIGHLIGHTING ON THE IDENTIFICATION PROCESS DURING VISUAL SEARCH

by Stephen Tse

The effect of highlighting formats has been shown to be situation specific and dependent upon many factors and contextual variables. This study investigated how three highlighting formats (color, blinking, and brightness) affected the identification process when presented as either the targets or distractors. Also investigated was whether prior exposure of information presented in a format had an affect on identifying subsequent information presented in a different format. Twelve students participated in a speeded two-choice response task that involved detecting a primed number presented in a certain format. Results showed that subjects were quick to identify targets when their format was bright or colored, and that performance was not adversely affected by the preceding format. As distractors, bright and blink formats adversely affected the identification of the target. Therefore, highlighting has tradeoffs and before applying highlighting in visual displays, the context should undergo a critical evaluation.

ACKNOWLEDGEMENTS

First of all, I would like to thank all three of my committee members for their valuable time amidst their busy schedules. I would like to thank Dr. Kevin Jordan for his assistance and guidance, while providing positive support throughout this research. I would also like to thank Dr. Walter W. Johnson for the many elaborate discussions we had on the phenomena of highlighting and highlighting usage. Finally, I would like to thank Dr. Kevin M. Corker for his contributions on the theoretical aspect of highlighting and attention allocation.

In addition, I would like to thank Mr. Rainer Gustin for programming this experiment and making timely modifications to the program code when necessary. I appreciate the guidance from Dr. Min-Ju Liao, who has been my mentor throughout this entire thesis process. I thank Ms. Sheila Holland, who reviewed this manuscript and provided valuable comments and suggestions. Finally, I would like to thank Dr. John Uhlarik for his detailed critical insights that helped shaped the final version of this thesis.

TABLE OF CONTENTS

SECTION	PAGE
INTRODUCTION	1
Highlighting	1
Highlighting Effects on Identification	7
The Present Experiment	12
METHOD	16
Participants	16
Apparatus and Materials	16
Design	16
Procedure	18
Dependent Variable	19
Stimulus Characteristics	20
RESULTS	20
DISCUSSION	30
Effective Salience	31
Effect of Prior Exposure on Identification	35
Voluntary vs. Involuntary Search	38
Conclusion	40
REFERENCES	42
APPENDIX	47

LIST OF TABLES

TABLE PAGE

1. Mean Response Time (ms) and Accuracy for the 3 (Target Position: Center, Offset, Absent) x 4 (Center Format: Standard White, Bright, Color, Blink) x 4 (Offset Format: Standard White, Bright, Color, Blink) Experimental Conditions. 22

LIST OF FIGURES

FIGURE	PAGE
1. Schematic representation of a typical experimental trial	17
2. Mean response time for the target position main effect	23
3. Mean response time for the center format main effect	24
4. Mean response time for center format by target position interaction	25
5. Mean response time for offset format by target position interaction	27

The Effect of Highlighting on the Identification Process During Visual Search

Since the amount of information displayed on a Visual Display Terminal (VDT) or another type of medium may be unlimited, an inevitable consequence is clutter. When searching a VDT (e.g., searching for an intruder aircraft on a cockpit display), critical information must be detectable and not obscured by clutter. Therefore, designers are faced with an inevitable tradeoff between information and clutter, since the more cluttered the display, generally the longer it will take to detect the target (Wickens & Yeh, 1997). Clutter is defined as "to fill or cover with scattered or disordered things that impede movement or reduce effectiveness" (Mish, 1988, p. 431). Not only does clutter adversely affect visual search, but it also affects information readout (Wickens & Yeh, 1997). That is, it may be difficult to identify an acquired target because of cluttered information that competes for attention. Therefore, clutter may lead to a "failure of focused attention caused by the competition for processing resources between close objects in space" (Wickens, 1992, p. 95). In aviation applications, display clutter and its impact on detection and salience during visual search continues to be a critical issue when time is crucial (Johnson et al., 1997).

Highlighting

One of the most researched techniques to resolve the clutter problem is the use of various highlighting (HL) formats for making pertinent information more conspicuous. Highlighting is simply the manipulation of certain elements in a display to segregate items in one group from those in another group. By accomplishing this segregation, human visual attention can filter wanted from unwanted information (Wickens & Yeh, 1997). In applied settings, where computerized visual displays are becoming more prevalent, the use of HL has become increasingly relevant and important because its main objective is to reduce the time to locate information by directing the user to the most pertinent information. In other words, HL may have a bottom-up or exogenous control over the locus of attention and has the ability to produce "pop-out" effects (Martens & Wickens, 1995; Yantis, 1993) which makes the highlighted item distinct from other items on a display. Because of this pop-out effect, the use of highlighting can direct the observer's scanning behavior toward these distinct items. Without highlighting, the scan behavior may progress with a top-down or goal directed locus of control.

Research indicates that HL may improve information processing efficiency (Philipsen, 1994), attract and direct attention (Fisher, Coury, & Tengs, 1985; Fisher & Tan, 1989; Spoto & Babu, 1989), increase target conspicuity (Thackray & Touchstone, 1991), and facilitate the search process (Donner, McKay, O'Brien, & Rudisill, 1991; Fisher, Coury, Tengs, & Duffy, 1989; MacDonald & Cole, 1988; Tan & Fisher, 1987). Therefore, the goal of HL is to display pertinent information with clarity and salience and to capture attention independently of clutter and density effects (Cahill & Carter, 1976). Since the user is often required to search through a vast amount of information on various display media to find a specific unit of information, the use of HL has the potential to facilitate the search process (Tan & Fisher, 1987).

Highlighting Costs

Unfortunately, depending on the context and circumstance, HL also has the potential to result in a performance decrement (Philipsen, 1994). In some cases, the use of HL produces a search performance cost (Fisher & Tan, 1989). This occurs when an irrelevant item (i.e., distractor) is highlighted and is more salient than the target. Therefore, a performance cost may occur since viewing a highlighted distractor will prolong the time necessary to detect the target. Fortunately, a highlighted distractor should only occur in rare circumstances, if at all.

Another cost of the HL phenomenon occurs when the target (rather than a distractor) is highlighted, but the type of HL format used is more of a detriment than a benefit. This may have the potential to result in performance that is worse than would be without any HL at all. Merely because an element is different and distinct from other elements of a display does not necessarily lead to a faster search rate. One example is the use of blinking. Blinking can be detected rapidly regardless of screen location because it attracts attention, but blinking stimuli may be difficult to read which may delay the overall search process (Thackray & Touchstone, 1991; Van Orden, Divita, & Shim, 1993).

In addition, highlighting too many items may be worse than having no highlighting at all (Cahill & Carter, 1976). The pop-out effect of HL might be reduced if there are too many items in a display that are highlighted. Furthermore, HL is often situation specific, so what may be beneficial in one context may be a detriment in another. Therefore, many factors will determine whether HL will serve as a benefit or a cost.

Highlighting Formats

A variety of HL formats have been investigated (Brown, 1991; Philipsen, 1994), but only a select few have been found to facilitate the search process. Of the many HL formats that have been investigated, the three that appear to most consistently facilitate the search process are *color*, *blinking*, and *brightness*. Although these salient discriminating features generally allow more rapid processing of important information, in any given context, these three formats can produce costs as well as benefits.

Color. Color (chromaticity) has gained the most consistent support as an effective HL format (Brown, 1991; Fisher & Tan, 1989; Kopala, 1979; Philipsen, 1994). Color has been found to support discrimination (Martens & Wickens, 1995), reduce search time (Thackray & Touchstone, 1991), enhance parallel processing (Van Orden et al., 1993), and it can be effective in a wide variety of contexts (Perlman & Swan, 1994). Additionally, color can be used for a global figure-ground segregation and grouping. In certain circumstances, color can provide a three-dimensional effect by chromostereopsis; that is, viewed against a black background, reds appear to pop-out toward the viewer while blues tend to recede (Preece et al., 1994, p. 93).

Christ (1975) conducted an extensive review of literature on the use of color coding on visual displays. The most clear cut finding was that when the color was known in advance and was unique for a specific target, color aided both search and identification. Christ also concluded that when identifying a feature within a target, color increased feature legibility compared to size, brightness, shape, and other parameters. However, color was less effective in aiding detectability compared to location and alphanumeric class.

An important caveat is that since color is a salient attribute, it may inhibit information integration of non-highlighted items (Wickens & Andre, 1990). The use of color may interfere with the speed of locating, and the accuracy of identifying, achromatic target attributes (Christ, 1975), which could severely limit its use in contexts where color is not the only feature of concern. In addition, searching for a set of targets is less cumbersome if all are of the same color (Christ, 1975). Andre and Wickens (1988) found that when participants had to integrate three relevant display parameters during an aircraft stall, it was more disruptive to integrate the information when different colors were used compared to a uniformly colored display. Finally, although color-coding may have semantic meaning and population stereotypes (e.g., "red" means danger), it does not have an ordinal hierarchy, as does brightness intensity (Wickens & Yeh, 1997).

Blinking. Intermittent blinking (or flashing) has also gained its share of support as an effective HL format (Thackray & Touchstone, 1991). The use of blinking can code either inclusion or exclusion (Smith & Goodwin, 1971), direct attention to an otherwise unnoticed target (Thackray & Touchstone, 1991), and in some cases, guide and cue attention toward static non-blinking targets (Van Orden et al., 1993). Some studies have indicated that blinking can improve search performance as much as 50% (Thackray & Touchstone, 1991; Van Orden et al., 1993). In addition, Thackray and Touchstone found that compared to either a color condition or a baseline control condition (i.e., non-flashing, non-colored), blinking (4 hz 125-ms on, 125-ms off duty cycle) was detected more rapidly regardless of screen location, changes in primary taskload, or monitoring fatigue.

Despite the potential to capture attention, there is a consensus among researchers that blinking should be used sparingly and possibly used only for warning purposes (Thackray & Touchstone, 1991; Van Orden et al., 1993). Although use of blinking can direct attention to unexpected targets, it can cause undue distraction and can also distract the observer if it remains on the display for a long period. Another problem with blinking occurs during identification. Specifically, blinking does not appear to adversely affect detection or localization, but during the "off" phase of a blinking cycle, the observer sometimes cannot identify or encode the information (Brown, 1991; Fisher & Tan, 1989). Therefore, identifying the optimal temporal parameters of blinking is important in contexts such as in a cockpit where encoding altitude and heading information of other aircraft in a timely manner is crucial for navigation and collision avoidance.

Brightness. Unlike blinking, brightness (luminance) can effectively highlight symbols without causing much distraction (Van Orden et al., 1993). Brighter targets can be discriminated from the background stimuli almost immediately through the preattentive process (Thackray & Touchstone, 1991). Increasing the luminance to increase the salience of a target can be advantageous, because at low luminance, targets are difficult to detect (Lit, Young, & Shaffer, 1971). The effectiveness of brightness depends on the baseline luminance of the elements on the display; generally, as the amount of luminance increases, the target becomes more salient up to some asymptote. In addition, luminance also depends on the contrast capabilities, illumination, and glare of the monitor (Philipsen, 1994).

There are some drawbacks when using luminance to enhance salience. First of all, the difference threshold (i.e., the smallest amount of difference in stimulus intensity in order to produce a noticeable change in sensation) needed to discriminate different levels of brightness is quite high; only a few levels of brightness intensity can be detected and distinguished from others without increasing search time. Furthermore, these levels have little if any consistent population stereotypes other than importance. Often, the brighter a target is, the more important it is considered (Wickens & Yeh, 1997).

The use of color, blinking, and brightness HL formats to facilitate the overall search process have gained the most support in empirical research. Note that there are additional "features" that are extracted early in visual processing such as size, tilt, curvature, and line ends (Treisman, 1986). However, because of display requirements, some of these features cannot be implemented in certain contexts (e.g., cockpit display). For example, although motion appears to be a highly salient stimulus, it would be inappropriate in symbolic displays that have positional requirements (Van Orden et al., 1993). Whichever format is implemented (whether motion, blinking, curvature, etc.), it must still be used in the correct context for HL to produce optimal performance.

Highlighting Effects on Identification

In a typical visual search task, once an item (highlighted or non-highlighted) attracts attention, the observer will eventually need to identify the specific item. Whether preceded by detection or other processes, the process of identification must eventually occur in order to extract the information from the specific item. In many cases, a higher level of cognitive processing must occur during the identification process such as word recognition and categorization (Brown, 1991). For the purposes of the present paper, the major focus is to determine how the legibility and readability of highlighted items affect the identification process during target acquisition. If the information linked with the item is not completely legible, then it will delay the response time to identify the stimulus and take action. The legibility of information during the identification process is critical, especially in the context of highlighting.

Effective Salience

The concept of salience is dependent on the relationship between the properties of the target stimuli and the non-target background stimuli. Items that are salient on a display may have the ability to capture attention automatically in a bottom up process (Yantis, 1993). The process of capturing attention can occur with or without the presence of a certain stimulus property. Since tasks are goal dependent, what may be salient in one context may not be as salient in another. For example, an empty seat in a theater may be salient if the present goal was to find a place to sit. Conversely, if the goal was to search for a particular person in a theater, the empty seat may no longer be salient since the task has changed. In addition, a blank area on a radar screen may be salient since it is unused space; this may capture an air traffic controller's attention, since aircraft can be allocated and redirected to the unused airspace. Similarly, having multiple aircraft within a certain region of a radar screen can also capture attention, since the goal is to maintain a minimal separation distance among several aircraft. Therefore, the ability to capture attention can occur with or without the presence of a stimulus property. For the purpose of the present experiment, salience is defined on how the presence (not the absence) of a stimulus property is able to affect performance.

One of the major goals of HL implementation is to make important items appear more salient. Otherwise, if the highlighted stimulus is not salient, it may not aid its detectability. The HL formats that preattentively pop-out and attract attention are those that are considered the most beneficial since they aid in the detection process. However, because of its salient attributes, the usage of HL may actually hinder and delay the identification process.

Highlighted Targets. Although a highlighted item may be different from the surrounding stimuli and therefore capture attention, it does not necessarily lead to an overall faster search rate. In other words, the added salience of an item may actually hinder the process. Two examples of HL formats that benefit the detection process but may delay the identification process are blinking and boxing (i.e., surrounding an object with a frame of thin lines). When the targets are blinking or boxed, they are very detectable, but during the identification process, problems of legibility may occur (Fisher & Tan, 1989). As mentioned earlier, blinking consists of an on-off phase, which is a highly effective way of attracting attention (Thackray & Touchstone, 1991). However, there are different rates of blinking which may have differential effects during the identification process. Employing a slow blink rate (1000-ms on, 1000-ms off duty cycle) may delay the identification since during the 1000-ms off phase of the blinking cycle, the observer cannot read the information since it would briefly disappear (Brown, 1991; Fisher & Tan, 1989). A tentative solution would be to employ a fast blink rate (100-ms on, 100-ms off duty cycle), but a rapidly blinking stiumlus is very distracting especially when the task is to read the information (Van Orden et al., 1993).

In addition, the use of boxing with its enclosed frame may serve as a distraction to the actual information (Fisher & Tan, 1989). Although it may be detected quickly, the boxing HL format causes a masking effect, and may interfere when the observer reads the actual information. Therefore, no matter how attractive or salient a highlighted target is, the search process may be delayed if difficulties in identification occur.

Highlighted Distractors. As mentioned earlier, there may be cases when a highlighted item serves as a distractor, and not a target. Not only does viewing a HL distractor lengthen the search process, but its salient presence on a display may hinder the identification of non-HL targets. Fisher and Tan (1989) found that some HL items (e.g., boxing and reverse video) might draw attention away from a target item. Another example is the use of blinking, which has been shown to distract the observer if it remains on the display for a long period (Thackray & Touchstone, 1991).

If an irrelevant stimulus (i.e., distractor) is salient, it may be difficult to filter out and may delay the reading of another object (Treisman, Kahneman, & Burkell, 1983). Treisman et al. noted that when two separate objects are present, it might be difficult to completely focus on one item because there is a competition for processing resources from the adjacent item. This is derived from resource models of attention that propose that there is a limited capacity of resources for mental activity with which people can allocate their attention (Proctor & Van Zandt, 1994, chap. 9). Performance will suffer when the demands of one task exceed attentional capacity. According to Treisman (1983), when attending to a target positioned in close proximity to a distractor, the distractor will interfere and attract processing resources away from the target. Furthermore, if the distractor is salient, the interference will be more pronounced. Therefore, HL has the ability to be distracting when it is applied to the non-target, which may have detrimental effects on identifying non-HL targets.

Effect of Prior Exposure on Identification

Treisman (1986) was interested in determining how an object's unity could be maintained when it transformed or changed location. Treisman devised a task that involved two primed letters briefly flashed in the center of two separate boxes (for a complete description, see Treisman, 1986). These empty boxes then shifted to a new location, and a letter appeared in only one of the boxes. Treisman found that when the final letter matched the primed letter and appeared in the same box, response time was 30-ms faster than when a different letter appeared, or when the primed letter appeared in the opposite box. These findings indicate that it takes more time to create or update an "object file" than it does simply to perceive the same object a second time. According to this finding and the "Feature Integration Theory" (Treisman, 1992; Treisman, 1993), when observers switch from one item to another, they are quicker to retain the same feature maps (switching from a red stimulus to another red stimulus) compared to switching between maps (red to green). Therefore, the question remains whether viewing a highlighted item may actually delay the process of identifying another item because the "feature maps" of highlighted items vs. non-highlighted (or other highlighted) items are fairly different. For example, there may be a delay when switching from a dynamic blinking stimulus to a static white stimulus since the feature maps of the stimuli are quite different. On the other hand, switching from a white to another white stimulus may be quicker because the feature maps (of the preceding white stimulus) are still in visual immediate memory and therefore, a recruitment of any new feature maps may not be necessary.

In a typical visual search task, a few items are often viewed before finding the actual target. Whether prior exposure of an item can have an effect on viewing a subsequent item has yet to be tested in the HL literature. Since highlighted items are intended to be salient and different from surrounding stimuli, there may be an added delay when switching from a salient item to a standard non-highlighted item, or vice versa. One example that has shown to delay the identification process is the "reverse video" HL format. Reverse video (foreground-background reversal in monochromatic displays) may be a hindrance since there is a polarity reversal, which may delay the recruitment of feature maps. For example, after searching through a display with white items on a black background, a reverse video effect on an item will display a black item against a white background. This will affect the consistency of the presentation and has been shown to increase response time to identify the item (Philipsen, 1994). The increase in response time may be attributed to the time necessary to recruit the new feature maps not only for the foreground information, but also the background information.

The Present Experiment

The main purpose of the present experiment was to determine whether certain HL formats affect participants' identification of a target in conditions where 1) the target was presented in a certain format, and 2) the distractor was presented in a certain format. In addition, the present experiment attempted to investigate whether the prior exposure of an item has an effect on viewing a subsequent item. Participants engaged in a speeded two-choice response task that involved a target priming stage and a target search stage. The target priming stage displayed a three-digit number in the center of the display. During the search stage, two numbers were presented in a certain format (e.g., bright and color). Participants were required to detect whether the primed number was present or absent on the display. In order to isolate the processing time associated with the identification process, participants were instructed to focus and confine their attention to a certain area in the display, before shifting attention elsewhere if necessary. The present study attempted to answer the following specific questions:

1. Which HL formats (i.e., color, blinking, or brightness compared to a standard condition) best facilitate identification? The goal was to determine how legible a target was and how quickly a participant could read a target when it was presented in a certain HL format. The identification process was tested in a condition where the target was located in the center. In a trial, a number was primed in the center of the screen. Following a 500-ms delay, two numbers appeared (one in the center, and one offset to the side). In the process of detecting the target, participants were instructed to view the center number before viewing the side number, if necessary. When the target was located in the center, the main task for the participant was to identify the center number and indicate with a keystroke that the target matched the primed number. Therefore, when the target was presented in the center, the lowest response time would indicate which format resulted in the quickest identification.

It would appear that color would increase feature legibility compared to a bright or blinking stimulus. When identifying a feature within a target, Christ (1975) found that color increased feature legibility compared to brightness and other parameters. Conversely, the HL format that should adversely affect identification would be the blinking stimulus. Blinking, with its dynamic qualities, is very distracting and may affect the identification or encoding of information (Brown, 1991; Fisher & Tan, 1989). Therefore, the first hypothesis of the present experiment was that color would aid in the identification process and that blinking stimuli would adversely affect the identification process.

2. Which HL format (i.e., color, blinking, or brightness compared to a standard condition) hinders the identification process? In other words, how does an adjacent highlighted distractor affect and interfere with the target identification? The condition in which the target was located in the center was used to determine how highlighting affected the identification of the target. However, the analysis will be on how the adjacent offset distractor of a certain HL format will affect the identification of the center target. Since participants were instructed to initially focus on the center number, there was no need to view the offset number since the target was already found. Therefore, any effect of the HL format of the offset number on a center target may indicate which HL formats are distracting and salient enough that they were difficult to filter out.

Thackray and Touchstone (1991) found that blinking could be detected regardless of screen location, changes in primary taskload, or monitoring fatigue. Although use of blinking can capture attention, it can also distract the observer if it remains on the display for a long period (Thackray & Touchstone, 1991; Van Orden et al., 1993). Therefore, a second hypothesis of the present experiment was that a blinking offset distractor would adversely affect identification of a center target (regardless of the HL format of the target), compared to the bright and color formats.

3. What, if any, effect does prior exposure of an item have on viewing a subsequent item? Specifically, is there a cost in switching from a "dim to dim" item, compared to switching from a "dim to colored" item. Since HL items are intended to be different from surrounding stimuli, there may be a cost when switching attention between "same" and "different" items. Feature Integration Theory would suggest that retaining the same feature maps when switching from feature to feature would be advantageous. Since the primed number was always displayed in standard white (dim) format, the participants should always start the search stage with this feature map. Therefore, when the target was located in the center, participants should respond the quickest when the center number was formatted in standard white as compared to the color, blink, and bright formats. The third hypothesis was that it would be quicker to process the same format than a different format, supporting the notion of feature maps in the Feature Integration Theory.

In summary, the main goal of the present experiment was to understand how three HL formats, color, blinking, and brightness (compared to a control condition), affected identification when the target was presented in a HL format, compared to when a distractor was presented in a HL format. Also investigated was whether prior exposure to an item would have an effect on viewing a subsequent item. In addition, since participants were given specific instructions to confine their search to the center before the offset number, a goal directed search (i.e., top-down) should have been adopted during the task. However, the salient qualities of HL may produce bottom-up effects. Therefore, it will be interesting to determine how bottom-up processes affect the top-down locus of control.

Method

Participants

Twelve university students participated in the present experiment. All received class credit for participation.

Apparatus and Materials

A Pentium with a MicroScan 4G AO1 color monitor with a 35.3 cm diagonal screen (640 x 480) was used for the present experiment. Viewing distance was approximately 75 cm.

Design

The present experiment was a 3 (**target position**: center, offset to the left or right, or absent) x 4 (**center format**: color, blinking, brightness, or a standard white control) x 4 (**offset format**: color, blinking, brightness, or a standard white control) within subjects design. A schematic representation of a typical trial is shown in Figure 1. The factor of **target position** indicated where the target was located. The target could be presented in one of three positions (i.e., the center, offset left, or offset right), or the target could be absent (i.e., no target appeared). The target was present on 50% of the trials, and it was absent on 50% of the trials. Of the target present trials, half of the targets were located in the center, and half were offset to either side. The targets offset to the side had an equal number of trials appearing in both the left and right side. The second factor of **center format** had four levels, and it indicated which format appeared in the center position. The four formats consisted of three HL formats (color, blinking, and brightness) along with a

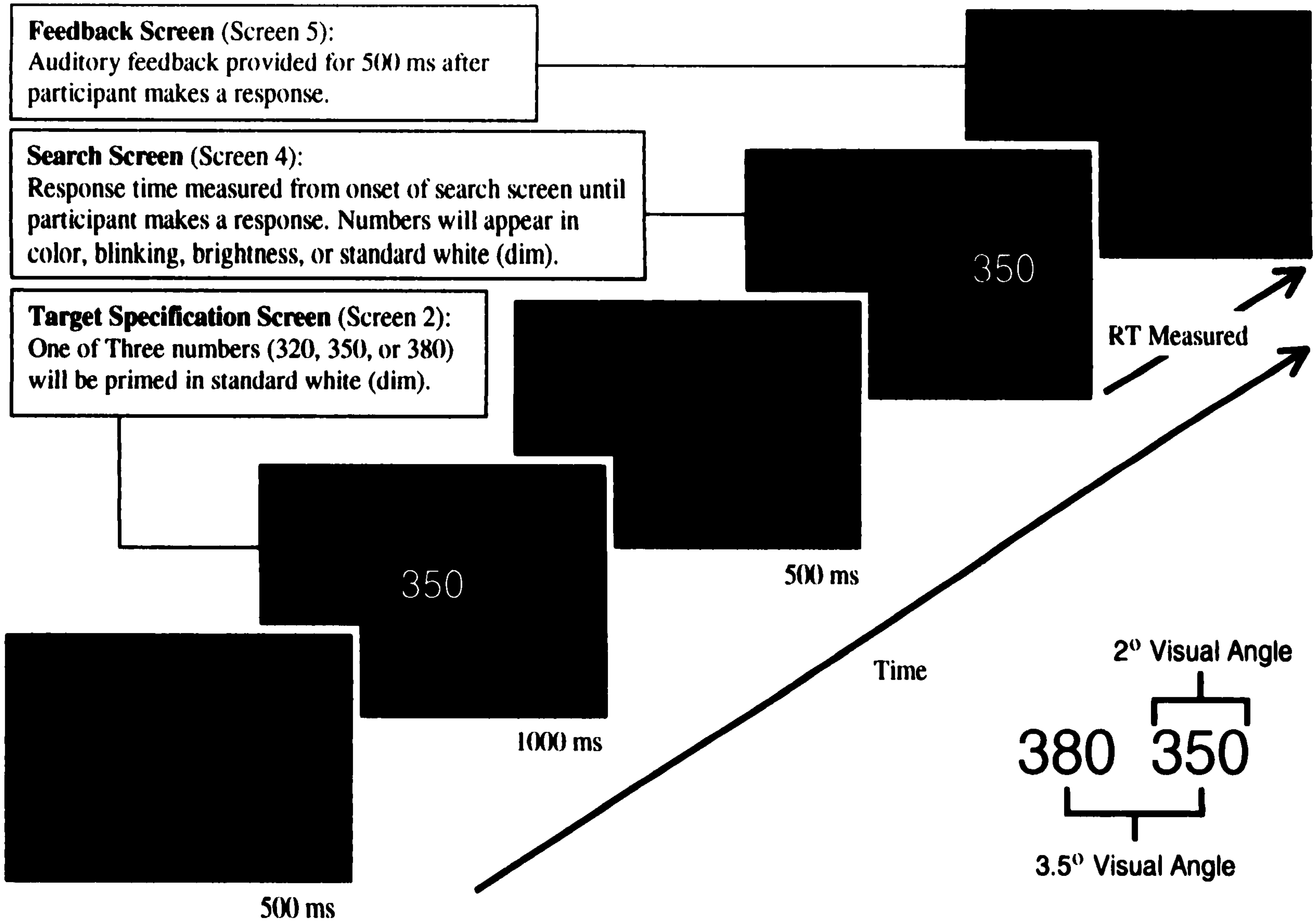


Figure 1. Schematic representation of a typical experimental trial.

standard white control condition. In addition, each of the four formats could also appear in the **offset format** position, which was the third factor.

Procedure

The critical parts of each trial included a target priming stage in which a number was displayed, and a search stage, where participants were expected to detect the primed target. The sequence for one experimental trial can be seen in Figure 1. A blank screen appeared before the start of each trial (500-ms). Following the 500-ms delay, a number ("320", "350", or "380") was primed as the target, appearing in the center of the display for 1000-ms (i.e., target specification screen). The primed number was the target that participants were asked to detect. Following this primed number, a blank screen appeared for 500-ms. The following search screen displayed two three-digit numbers (one in the center and the other offset to either the left or right side). These two numbers subtended 2 deg of visual angle when viewed from a distance of 75 cm. The combined distance from the center of both numbers was 3.5 deg of visual angle. Either of these numbers could be formatted in red, intermittent flashing, enhanced brightness, or a standard white (dim) format. Note that the format provided no cue to target location. In other words, there was no advantage by focusing on a particular format (i.e., color) since each format was completely balanced and was designated as either the target or distractor an equal number of times. Participants were instructed to locate the number that was primed as the target and press "Yes" if it was present; if the participant did not detect the primed target number, a "No" button was to be pressed. Response time was measured from the onset of the search screen, until a button was pressed. Participants were instructed to search the center number first, then search the offset position if necessary. This instruction was mainly to isolate and identify the processing time associated with identification when the target was (1) in the center and (2) in the offset position. If participants followed this instruction, the results would reveal how the bottom-up effects of HL formats can affect the top-down locus of control. Feedback was provided for 500-ms immediately after the participant made a response by either a pleasant "click" (i.e., correct) or unpleasant "boing" (i.e., incorrect).

Dependent Variable

The dependent variables were the response time (RT) and accuracy to detect the presence or absence of the primed number. Response time was measured from the onset of the two three-digit numbers in the search screen (Figure 1) until the participant pressed one of two keys on a keyboard indicating whether the target was present or absent from the display. Half of the participants were instructed to use their right finger to indicate target present, and their left finger for target absent, and the other half did the reverse. Participants were instructed to respond as quickly as possible without sacrificing accuracy. A 90% accuracy criterion for correct identification was set for data acceptable analysis, and all participants met this criterion. Each participant received 16 blocks of 48 trials for a total of 768 trials, which took approximately 40-min to complete. Participants received three one-min breaks during the 40-min session. Each block of 48 trials constituted the 3 x 4 x 4 factorial combinations. Blocks were balanced for factors and presented randomly with a half-sec duration between each trial.

Stimulus Characteristics

The three primed target numbers consisted of three digits (320, 350, or 380) and varied randomly across trials. Either of the two numbers not used as the primed target could serve as a distractor for a given trial. For example, Figure 1 shows a target present trial. Here, the primed number is 350, while the distractor number is 380. On a target absent trial where the primed number is 350, the distractor number will be 320 and 380. The three numbers were designated as either targets or distractors an equal number of times.

The initial presentation of the primed target (i.e., target specification screen in Figure 1) was always displayed in standard white (i.e., control condition) on a black background. On the search screen (Figure 1), the numbers were presented in any of the three HL formats in addition to the standard white format. The font used for all numbers in this experiment was Arial (24 point). The standard white format was dim white (RGB value: 180, 180, 180). The "bright" white format employed the maximum brightness level on a desktop computer (RGB value: 255, 255, 255). Red (RGB value: 255, 0, 0) was used for the color condition. Finally, a blinking format of 5hz, 100-ms on, 100-ms off duty cycle was implemented. The blinking format had the same intensity as the standard white format (RGB value: 180, 180, 180.)

Results

The target-present and target-absent trials were analyzed separately. For the target-absent trials, a 4 (center format: color, blinking, brightness, and standard white) x 4 (offset format: color, blinking, brightness, and standard white) repeated measures analysis of variance (ANOVA) indicated no statistically significant main effects or interactions (Overall Mean RT = 754 ms). The response time and accuracy data for the target-present and target-absent conditions can be seen in Table 1.

For the target-present trials, a 2 (target position: center and offset) x 4 (center format: color, blinking, brightness, and standard white) x 4 (offset format: color, blinking, brightness, and standard white) repeated measures ANOVA was conducted for all correct responses (96.4% correct responses). One extreme outlier (RT = 23.5 s) was discarded from the data set; all other response times were below 6 s. Analysis of the target present trials indicated main effects for **target position,** $F(1, 11) = 173.40$, $p < .001$ (Figure 2), and **center format,** $F(3, 33) = 3.37$, $p = .03$ (Figure 3). For the **center format** main effect, a subsequent Newman-Keuls post hoc analysis showed significant differences between color and each of the other three format conditions, $F(4, 33) = 3.83$, $p < .05$; color yielded the quickest RT. In addition to the main effects, a two-way interaction of **target position** by **center format** approached statistical significance, $F(3, 33) = 2.47$, $p = .079$ (Figure 4). Further analyses separating the two target positions showed a marginally statistically significant effect for the center format when the target was located in the center, $F(3, 33) = 2.86$, $p = .052$ (Figure 4a, marginal means derived from Table 1). There was a statistically significant effect of center format when the target was located in the offset position, $F(3, 33) = 2.90$, $p = .05$ (Figure 4b, marginal means derived from Table 1). A subsequent Newman-Keuls post hoc analysis showed a significant difference between the color and bright format, $F(4, 33) = 3.83$, $p < .05$, with color yielding the quickest RT. Finally, there was a two-way interaction of **target position** by **offset**

Table 1.

Mean Response Time (ms) and Accuracy for the 3 (Target Position: Center, Offset, Absent) x 4 (Center Format: Standard White, Bright, Color, Blink) x 4 (Offset Format: Standard White, Bright, Color, Blink) Experimental Conditions.

Center Target

Center Highlighting (columns); Offset Highlighting (rows)

	SW	Br	Co	Bl	M
SW	**605** 97%	**609** 99%	**607** 94%	**647** 95%	617
Br	**641** 94%	**632** 95%	**620** 96%	**658** 97%	638
Co	**637** 97%	**591** 95%	**592** 99%	**601** 99%	605
Bl	**641** 98%	**616** 99%	**649** 96%	**648** 99%	638
M	631	612	617	638	

Offset Target

Center Highlighting

	SW	Br	Co	Bl	M
SW	**770** 93%	**748** 94%	**698** 95%	**741** 97%	739
Br	**732** 97%	**760** 95%	**710** 97%	**737** 99%	735
Co	**745** 89%	**781** 89%	**710** 94%	**793** 95%	757
Bl	**741** 94%	**758** 92%	**727** 95%	**711** 97%	734
M	747	761	711	746	

Target Absent

Center Highlighting

	SW	Br	Co	Bl	M
SW	**721** 98%	**786** 98%	**746** 97%	**752** 98%	751
Br	**751** 96%	**758** 97%	**722** 97%	**742** 96%	743
Co	**751** 98%	**762** 96%	**737** 98%	**740** 97%	748
Bl	**764** 97%	**775** 97%	**783** 98%	**764** 97%	772
M	747	770	747	750	

Legend:

SW - Standard White
Br - Bright
Co - Color
Bl - Blinking
M - Marginal Means

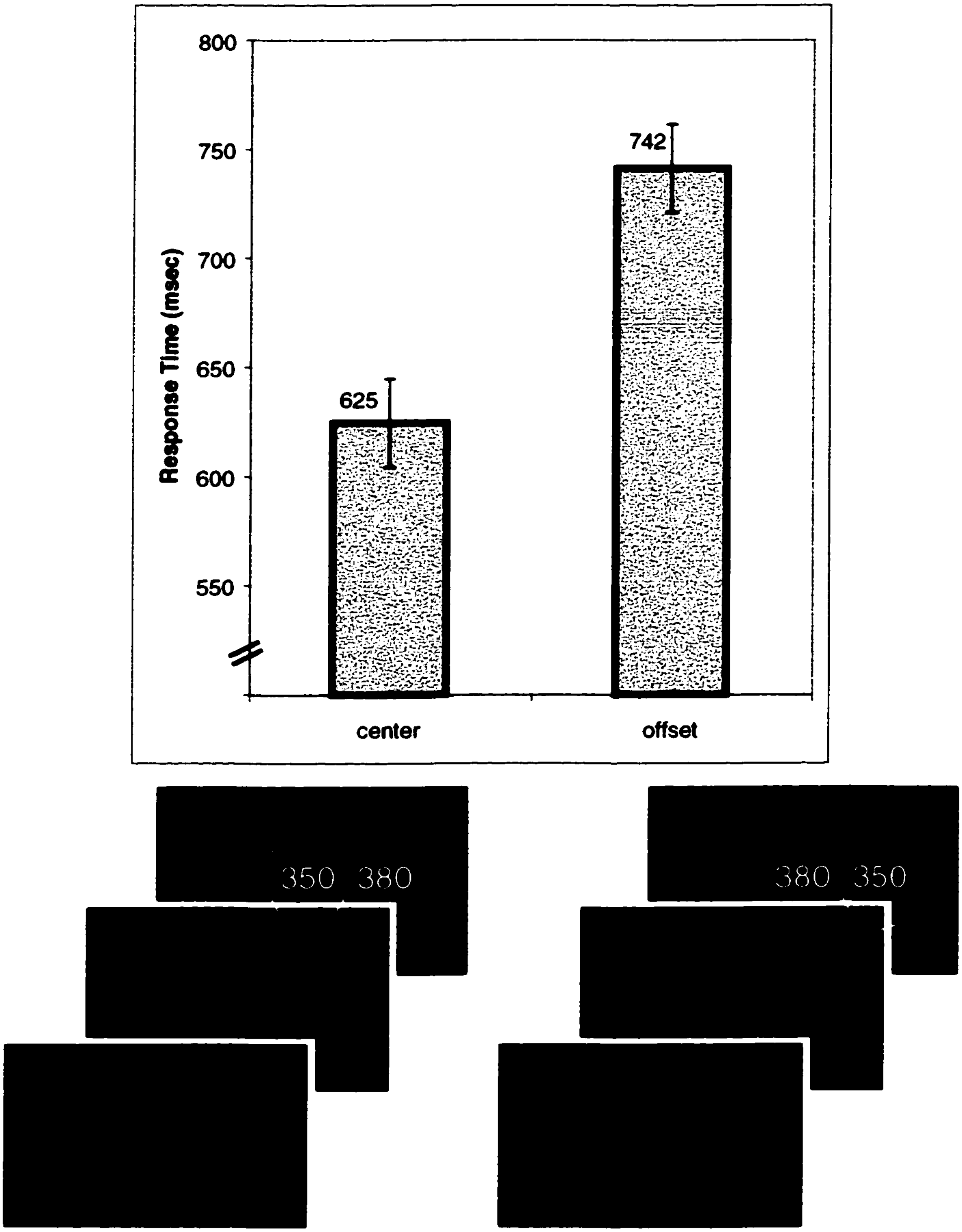


Figure 2. Mean response time for the Target Position Main Effect (p. < .001).

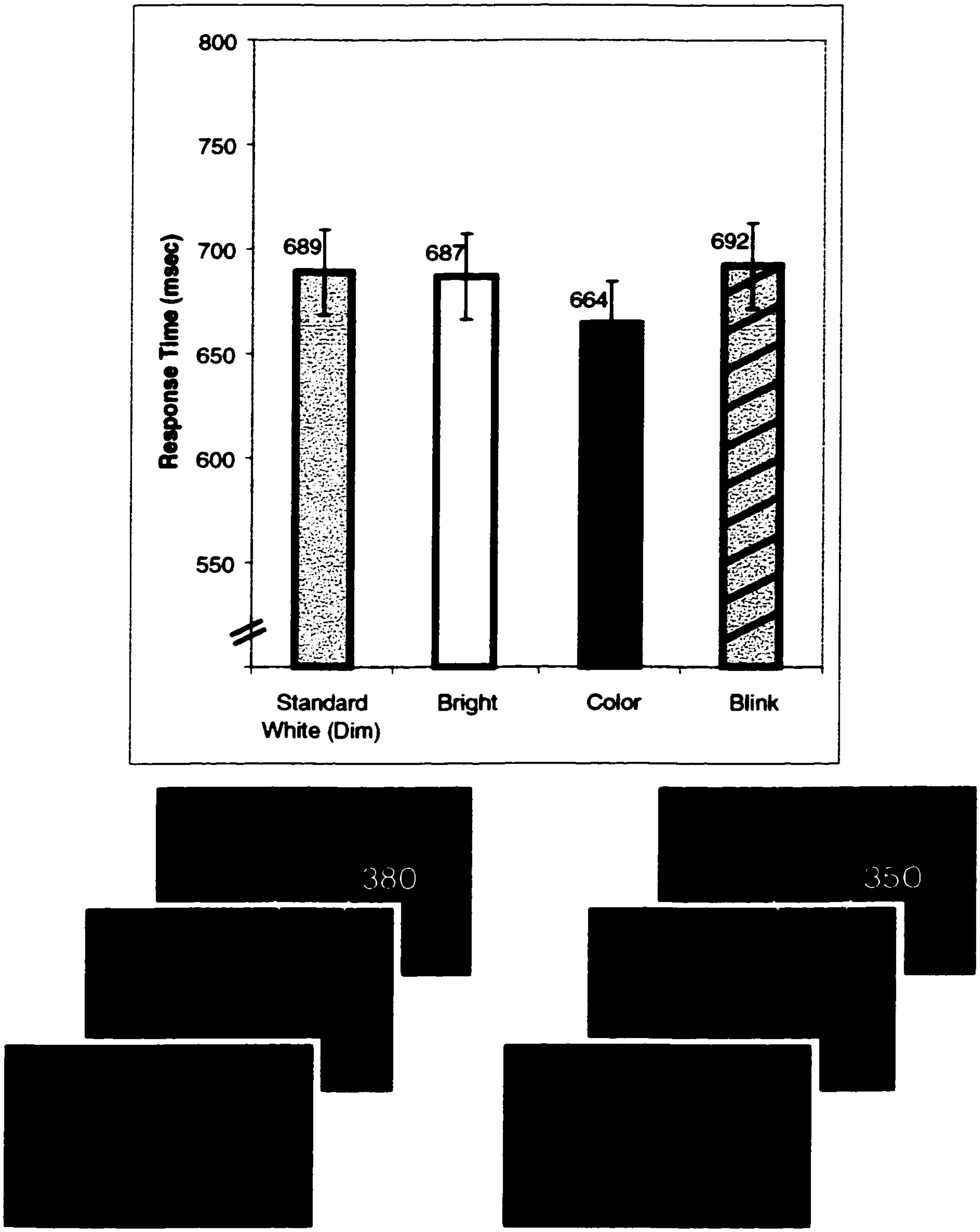
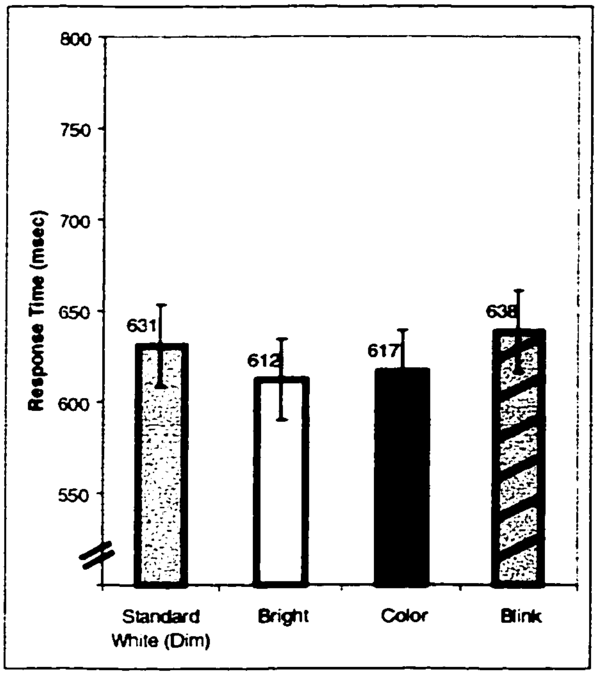
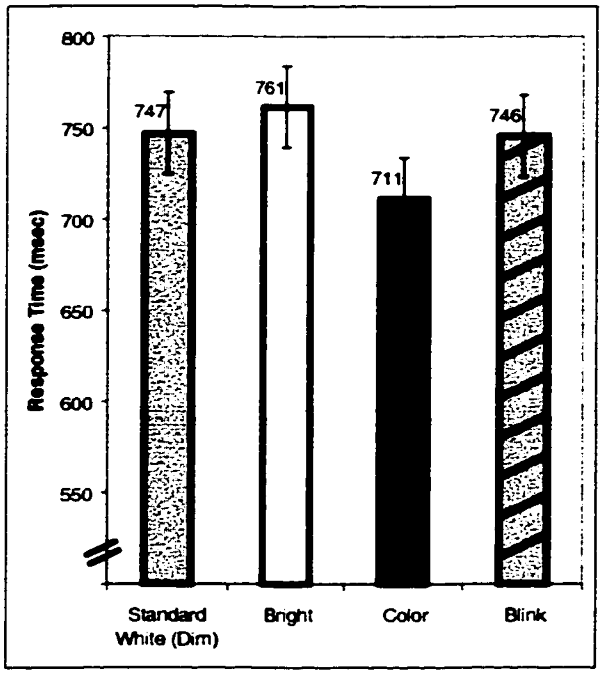


Figure 3. Mean response time for the Center Format Main Effect (p. = .03).



4a. Response time for center format when target was located in the center position (p. = .052).



4b. Response time for center format when target was located in the offset position (p. = .05).

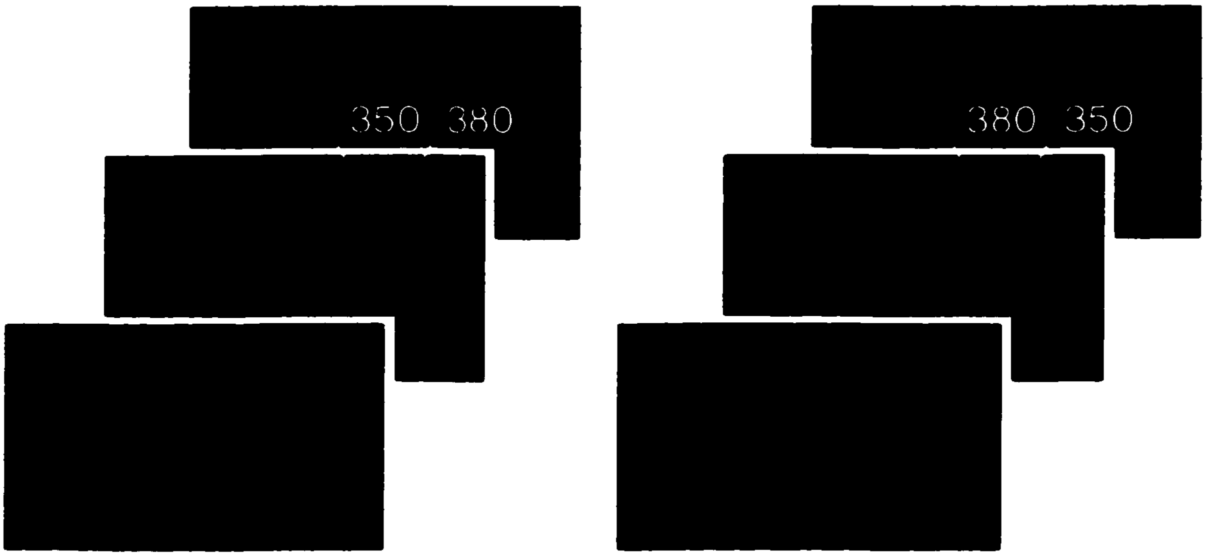


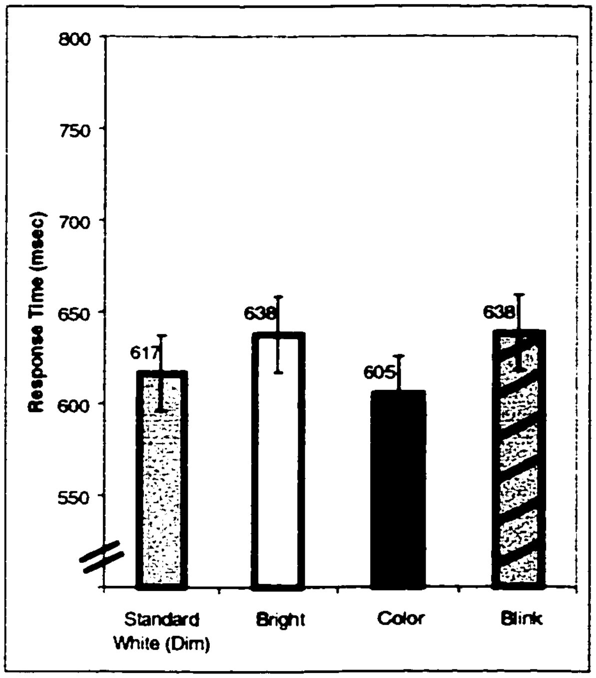
Figure 4. Mean response time for Target Position by Center Format Interaction (p. = .079).

format, $F(3, 33) = 4.09$, $p = .014$ (Figure 5). Further analyses separating the two target positions showed a marginally statistically significant effect of offset format when the target was located in the center, $F(3, 33) = 2.87$, $p = .051$ (Figure 5a, marginal means derived from Table 1). There was no statistically significant effect of offset format when the target was located in the offset position, $F(3, 33) = 1.27$, $p = .30$ (Figure 5b, marginal means derived from Table 1).

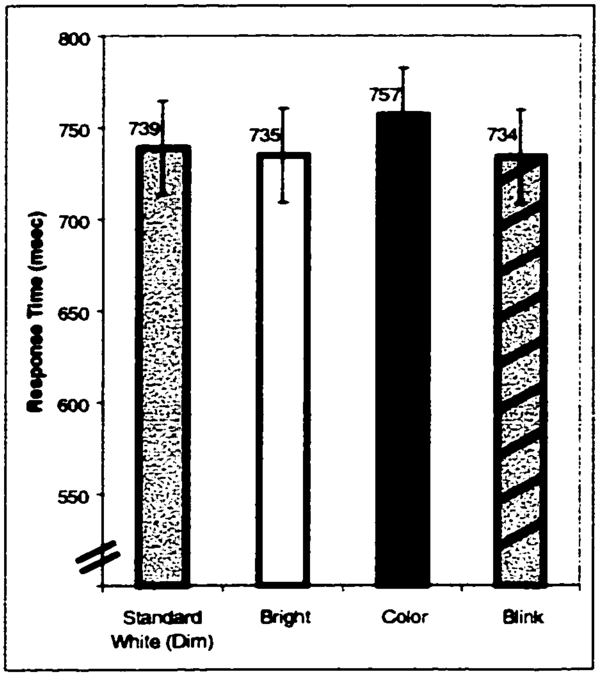
The statistically significant main effect of **target position** (Figure 2) showed that the targets in the center position (RT = 625 ms) were located more rapidly than the targets on the offset position (RT = 741 ms). This finding was expected since participants were instructed to search the center position first.

The statistically significant main effect for **center format** (Figure 3) indicated that participants responded the quickest during the color condition (RT = 664 ms) compared to the bright (RT = 687 ms), standard white (RT = 689 ms), and blinking conditions (RT = 692 ms). Since there was an interaction of **target position** by **center format**, a separate analysis is necessary to understand how the different formats affect the identification process.

For initial understanding of the effects of HL on identification, it is informative to analyze the **target position** by **center format** interaction. Figure 4a shows the response times for the center format condition (collapsing across the 4 offset formats) when the target was located in the center position. This condition mostly reflects with which formats the target was easily identified since this was the participant's first fixation of any relevant information. Remember that participants were instructed to search the center



5a. Response time for offset format when target was located in the center position (p. = .051).



5b. Response time for offset format when target was located in the offset position (p. = .29).

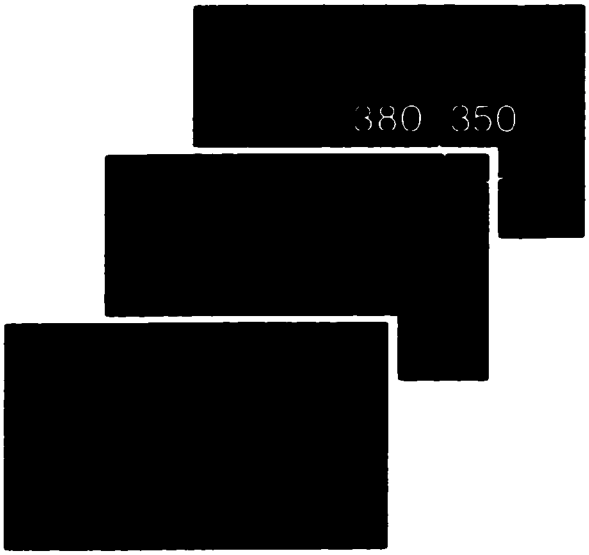


Figure 5. Mean response time for Target Position by Offset Format Interaction (p. = .014).

position first, and therefore there was no need for the stimulus to attract attention since attention was already allocated there. Since the target was located in the center, there was no need for participants to switch from the center and identify the side since the target was already found. Therefore the main task during this condition was to identify the center number and make a response. Participants responded more quickly when the target in the center was bright (RT = 612 ms) or colored (RT = 617 ms), compared to the standard white (RT = 631 ms) and blinking formats (RT = 638 ms).

Figure 4b shows the response times for the center format condition (collapsing across the four offset formats) when the target was located in the offset position. This condition may involve several processes. In this condition, the participant would initially identify the center number, and then switch away from it since it was not the target. The target was located offset to the side, and therefore, while participants were in the process of identifying the offset number, the center number was now a distractor. Participants responded the quickest when the format in the center was color followed by the blinking, standard white, and bright (RT = 711, 746, 747, 761 ms respectively) formats. A Newman-Keuls post hoc analysis showed a significant difference only between the color and bright format.

To analyze the affect of the center format conditions on the identification of the offset target conditions, it is necessary to eliminate the response times that are attributed mainly to identification. Subtracting the valid response times for the center target from the offset target conditions provides a first indication of which formats were distracting and difficult to filter out. The resulting means for the standard white, bright, color, and blink formats were 116, 149, 94, and 108 ms, respectively. Therefore, it appears that the bright format of a center distractor was very distracting and difficult to filter out. On the other hand, when the center distractor was red, the quickest response times were recorded which indicates that it was not very distracting or salient when attention was focused on the offset target. Note that this is just an inference, and other factors such as the amount of movement time to switch to the offset position may also play a role. Otherwise, the center format conditions (Figures 4a and 4b) initially support the assumption that color was efficient in terms of identification and was not salient when it served as a distractor. What may be interesting is the tradeoff of the bright HL format. When analyzing the center format conditions, the bright format in the center yielded the quickest response time when the target was in the center, but it yielded the longest response time when the target was on the offset position. This may indicate that although bright items were quick to identify, they were very distracting and difficult to filter out.

A significant interaction was found for the **target position** by **offset format**. Figure 5a shows the response times for the offset format condition (collapsing across the four center formats) when the target was located in the center position. This condition mostly applied to how adjacent salient distractors affect identification, and specifically indicates which formats were distractive enough that they were difficult to filter out. Note that if the target was in the center position, there was no need to fixate at the offset position since the target was already in the location to which attention was directed. In other words, there was no need to switch to the offset position. However, this apparently does not mean that the distractor on the offset position failed to play a role. Possibly, the format on the offset position could have been distracting and difficult to filter out. Although marginally significant, the bright (RT = 638 ms) and blinking HL formats (RT = 638 ms) on the offset position resulted in longer response times. This suggests that these two formats were salient enough to distract processing of the center target compared to the color (RT = 605 ms) and the standard white formats (RT = 617 ms). In other words, the bright and blinking formats were difficult to filter out, which delayed participants from quickly identifying the desired (center) target.

There was no significant effect for the offset format when the target was located in the offset position. Figure 5b shows the response times for the offset format condition (collapsing across the 4 center formats) when the target was located in the offset position. Since the target was located offset to the side, the side number was the second number viewed. Therefore, after identification of the center number (i.e., distractor), participants would need to switch to the side and identify the offset number (i.e., target).

Discussion

The main purpose of the present experiment was to determine whether certain HL formats affect participants' identification of a target in conditions where 1) the target was presented in a certain format, and 2) the distractor was presented in a certain format. Also investigated was whether the prior exposure to an item had an effect on viewing a subsequent item. Analyses of the data indicated that there were tradeoffs for some formats as a function of their salience.

Effective Salience

One of the major goals of HL implementation is to facilitate the detection process by making important items appear more salient. Although a salient item may facilitate the detection process in a visual search task, the present experiment found that some salient HL formats adversely affected the identification process.

Highlighted Targets. The first goal of the present experiment was to determine how legible a target was and how quickly a participant could read a target when it was presented in a certain HL format. Colored targets were hypothesized to increase feature legibility. Color targets as well as bright targets were found to be more readable and legible compared to the blinking and standard white formats. This was based on the finding that the color format in the center yielded a lower response time when the target was also in the center (Figure 4a). Therefore, part of the first hypothesis was supported in that color aided the identification process. The finding that color was efficient in terms of identification is consistent with previous studies (Luder & Barber, 1984; Tan & Fisher, 1987). In addition, Luder and Barber found that color provided a significant advantage for identification when the search task was less demanding, as it was in the present experiment.

Bright targets were also quick for participants to identify. Brown (1991) tested several HL formats under the identification stage and found that greater levels of brightness-contrast reduced search times. The bright HL format in the present study, employing an increase of 30% luminance intensity over the standard white format, and a RGB value of 255, 255, 255, was the maximum brightness intensity for a desktop computer.

Furthermore, the bright HL format was displayed on a black background, and viewed in a dimly lit room. This combination of factors most likely facilitated the identification process, since luminance is dependent on the contrast capabilities of the monitor, illumination, and glare (Philipsen, 1994).

Blinking, with its dynamic qualities, was hypothesized to adversely affect identification. Indeed, blinking was found to hinder the identification of information since it yielded the longest response time when the target on the center was blinking (Figure 4a). This finding is not surprising since there was a 100-ms on, 100-ms off duty cycle, which possibly affected the identification stage. A 100-ms on, 100-ms off duty cycle is considered a fast blink rate, and this rapid temporal modulation is very distracting especially when the task is to read the information. If the goal was to increase the legibility of information, a slower blink rate would be recommended (i.e., 1000-ms on, 1000-ms off duty cycle), but identification can only occur during the "on" phase of the blinking cycle. Unfortunately, employing a slower blink rate may possibly delay the detection process.

The deterioration of identification associated with the blinking HL format supports part of the first hypothesis of the present experiment. In addition, the negative effects of blinking on identification were also reported in previous studies (Fisher & Tan, 1989; Smith & Goodwin, 1972). Blinking is optimal when a target needs to be localized and detected, but not for identification because of its on-off phase (Fisher & Tan, 1989).

Highlighted Distractors. The second goal of the present experiment was to test how the identification process is hindered when a distractor is presented in one of the HL formats. This condition might have indicated which formats attracted attention and were salient enough that they were difficult to filter out. In terms of salience, the color format did not appear to be too distracting. When the target was located on the center, the color format in the offset position (Figure 5a) did not adversely affect the identification of the center target compared to the bright and blinking formats. This indicates that color was fairly easy to filter out and did not attract as much attention. Therefore, it appears that it is possible to preattentively filter out color. Brown (1991) found that color was beneficial for drawing attention to a specific location in a display. However, in that study, color was used with an enclosed frame (i.e., boxing), and this redundant coding possibly facilitated the search process. Kopala (1979) noted that the performance advantage with color might be greater with more complex and task demanding displays. Kopala used color coding for a flight performance task in a highly dense situation display. The present study was very simple involving only two items, and therefore, the salience of color was not fully maximized.

As stated earlier, blinking as a HL format was very beneficial for attracting-distracting attention. Thus, the second hypothesis was that a blinking offset distractor would adversely affect identification of a center target. The blinking distractor in the offset position was found to delay participants from identifying the center target (Figure 5a). The offset blinking distractor may have attracted processing resources away from identifying the center target. In other words, there may have been a filtering cost that elevated the response time. Blinking was very attractive and may have provided visual separability on the display. Therefore, the second hypothesis was supported in that the distractor blinking format adversely affected the identification of a target. This finding supports previous studies which indicated that blinking is a highly effective way of attracting or distracting attention (Smith & Goodwin, 1971; Thackray & Touchstone, 1991; and others).

Markowitz (1971) noted that blinking could provide the most discriminable stimulus when there is temporal and spatial uncertainty, combined with a high taskload. The present experiment provided temporal and spatial certainty combined with a low taskload and blinking was still discriminable. Therefore, blinking is very attractive and can be found quickly in most types of display media. Thackray and Touchstone also found that blinking targets can be found quickly anywhere in the display including the periphery. However, they noted that blinking is such a strong and compelling cue that its attractive features must be weighed against its possible potential for distraction. Blinking items are very difficult to filter out, and they can distract observers, making searches for non-blinking items more difficult.

To preserve the legibility of important information, there have been suggestions to present important information in a steady, legible form while attaching a blinking stimulus in near proximity to attract attention (Smith & Goodwin, 1971). One way of accomplishing this is to employ a blinking arrow in close proximity to a static non-blinking target. This would appear to preserve the legibility of the important information, while still having the perceptual salience of the proximal blinking feature. However, based on the results of this study, blinking is distracting and difficult to filter out. Although a blinking arrow may guide attention toward a non-blinking target, once attention is shifted to the correct location, the blinking stimulus may be difficult to filter out and could continue to occupy some attention resources. Future research is needed to resolve whether a blinking stimulus in close proximity to a target will be a benefit or a detriment.

Brightness had very similar effects to blinking in terms of attracting attention. The bright HL format was also salient and had the ability to attract or distract attention when it was not the object of focus. This was supported when the distractor bright HL format in the offset position delayed identification of the target in the center (Figure 5a). Therefore, problems will arise when features other than targets are salient, since these distractors may inhibit the focus of attention on surrounding material.

Effect of Prior Exposure on Identification

The third interest of the present experiment was to understand if the exposure of a previous item has an effect on viewing a subsequent item. Specifically, how does viewing the primed number in standard white affect viewing the center target (during the search screen) in a different format? This is a concept adopted from the Feature Integration Theory (Triesman, 1986; Triesman, 1992; Triesman, 1993) that suggests that it takes longer to create or update an object file of a new item than it does simply to perceive the same object a second time. The theory postulates that in order to perceive individual objects in the external world, visual attention will need to locate and integrate one or several feature maps in order to represent the object attended to. A quick synopsis of feature maps is provided.

Treisman's notion of feature maps (Treisman, 1993, Treisman & Souther, 1985) are the lowest level that appears in a recognition framework, and originate as the visual system codes a certain number of simple and useful properties in a "stack" of maps. These maps have evolved as a result of detectors responding in parallel to the different features across the visual scene. Perceptual features such as color, orientation, and shape are separately registered in these different maps. For example, if a visual stimulus consisted of a purple square, at minimum, one would need to integrate a color (i.e., purple) and shape (i.e., square) feature map in order to represent the purple square. As there are different maps between features (e.g., color, orientation, and shape), there may also be separate maps within dimensions (i.e., different shades of a certain color). To visualize a purple square, hypothetically one may need to integrate as many as six different maps just to perceive a "purple" "square": two color maps (i.e., blue and red), two maps for vertical lines, and two maps for horizontal lines (i.e., to form a square). Therefore, the feature maps coded in our visual system may have an infinite number of levels. Since highlighted items usually consist of additional features, the theory would suggest that more maps would need to be recruited to represent the new highlighted item. The question remains whether these additional features will require more time to recruit (and therefore lengthen response time). Since each highlight format has distinctive features that make them unique, some highlight formats may be quicker to recruit than others.

According to the Feature Integration Theory, when switching between items of different attributes (e.g., color and blink items), there would be an added delay when viewing the subsequent item since it consists of a set of different feature maps. This was supported in one of Treisman's studies (Treisman, 1986) mentioned earlier in which viewing a new item took 30-ms longer compared to viewing the same item twice.

On the contrary, the present experiment found some different results that may be difficult to interpret when compared with the Feature Integration Theory and Treisman's (1986) findings. The present experiment found that it was quicker to process a different HL format than the same format, thus opposing the third hypothesis. In a typical trial sequence in the present experiment, a number in standard white format was primed in the center of the screen. Following a half-second delay, two numbers appeared (one on the center and one offset to the side). When targets were located in the center (which comprised 25% of all trials), this indicated that the number matched the primed number. The only difference was that the number could be presented in one of four formats (i.e., color, blink, bright, or standard white). According to Treisman's findings, the standard white format should have produced the quickest response time, since the primed number was also displayed in standard white; therefore, it was not necessary to recruit any feature maps and create a new object file. However, this was not the case. The quickest formats to process were the bright and color formats.

Obviously, there are differences in the present experiment and the task employed by Treisman (Triesman, 1986). The current task involved numerics coded with different HL formats, whereas Treisman's task only used letters. In addition, for those 25% of the center target trials, the primed number appeared in the same location masked by a half-second delay, whereas the letter in Treisman's task shifted to a new location. A reasonable suggestion would be that participants in the present experiment viewed the target as a new item, instead of the same item masked by a temporary delay. Therefore, there was a need to re-update the object file. If this is not the case, and participants interpreted both numbers as the same object, it is interesting why the standard white format did poorly compared to the color and bright HL format. The feature maps for the standard white format should have still been in visual immediate memory, and this would have facilitated processing when the primed number was perceived the second time in standard white. Perhaps one shortcoming of the present experiment was that the primed number was always displayed in standard white, and never primed in any of the other three HL formats. Therefore, participants may have "tuned out" the standard white format and solely focused on the three-digit number. Otherwise, the findings from this experiment may suggest that some highlighted formats are quick to process, regardless of whether that item was previously viewed. Furthermore, Triesman and Souther (1985) indicated several features that were extracted early in visual processing; two of these included color and contrast (i.e., brightness), which lends support to the findings of this study. Therefore, although the present experiment was not a direct test of the Feature Integration Theory, the data indicates that certain highlighted formats (with its additional salient features) can be quick to identify when compared to the control condition.

Voluntary vs. Involuntary Search

The findings of how certain highlight formats affect the identification process may have some important implications in search behavior. The control of spatial attention during visual search can be either voluntary or involuntary (Remington, Johnston, &

Yantis, 1992). Voluntary search occurs as the observer employs a goal directed search. Attention is shifted to certain items on the visual display in a voluntary manner based on the observer's deliberate intent. This is often referred to top-down or endogenous control over the locus of attention (Yantis, 1993). Therefore, visual search is assumed to be under conscious, strategic control of the observer.

In contrast, involuntary search occurs when search behavior is "guided" without the observer's deliberate intent. Involuntary search is stimulus driven and attention may be redirected if salient items capture the observer's attention. This is often referred to as bottom-up or exogenous control over the locus of attention. This behavior is quite reflexive and automatic, and properties of the stimulus can capture attention independently of the observer's intentions (Yantis, 1993).

Effective information selection during visual search will depend upon a balance between both voluntary and involuntary search. There are several debates over which locus of control (i.e., voluntary vs. involuntary) occurs during attentional capture. Some have argued that the locus of attention is completely involuntary (Theeuwes, 1994), while others argue that attentional capture applies only to certain unique stimulus properties (Yantis, 1993). Futhermore, others argue that attentional capture is completely contingent on top-down factors (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). It is not the intent of the current thesis to resolve the research findings of the processes of attentional control and determine which locus of control is more dominant. The purpose is to briefly shed some light on how the findings of this study relate to voluntary and involuntary search.

In the present experiment, participants were instructed to confine their scanning behavior to certain areas of the display before others. For example, participants were instructed to always search the center position before searching the side if necessary. Therefore, participants were expected to adopt a top-down voluntary control behavior. As participants engaged in a top-down locus of control, some formats (i.e., bright and blink) produced bottom-up effects that interacted and interfered with top-down goal directed behavior. Take for example the condition where the offset format was analyzed when the target was located on the center (Figure 5a). In this condition, the target was already in the center, and there was no need to switch to the side. However, the salient attributes of the offset blinking and bright formats produced bottom-up effects that increased the response times when viewing the center target. Color, on the other hand, was not very distracting at all and did not appear to adversely affect top-down behavior compared to the blink and bright formats. Therefore, it appears that adopting a top-down locus of control can be affected by bottom-up factors when salient items like blink and bright formats are in close proximity.

Conclusion

It is difficult to integrate the findings of this experiment to all previous studies on highlighting and come up with a definitive conclusion of the costs and benefits of each highlighting format and highlighting usage in general. This is attributed to the number of diverse factors investigated in previous studies such as density, validity, taskload, display medium, redundant coding, and eccentricity, among others. The present experiment attempted to understand how the salient attributes of certain highlighted formats affect the identification process. When the targets were presented in different highlighting formats, bright and color targets were the quickest to identify. When distractors were presented in a certain highlighted format, bright and blink distractors adversely affected the identification of the target. In other words, bright and blink formats were very distracting and difficult to filter out. Finally, it appears that some formats are quick to identify (i.e., bright and color), and are not influenced by the exposure of the preceding item. Therefore, highlighting effects was situation specific in that some highlighted formats were beneficial in one process of a search task but were also a detriment in another process. A tentative conclusion is that there will be tradeoffs when highlighting is implemented and careful consideration should be taken to understand the specific context before applying highlighting in visual displays.

References

Andre, A. D., & Wickens, C. D. (1988). The interaction of spatial and color proximity in aircraft stability information displays. Proceedings of the Human Factors Society 32nd Annual Meeting (pp. 1371-1375). Santa Monica, CA: Human Factors Society.

Brown, T. J. (1991). Visual display highlighting and information extraction. Proceedings of the Human Factors Society 35th Annual Meeting (pp. 1427-1431). Santa Monica, CA: Human Factors Society.

Cahill, M. C., & Carter, R. C. (1976). Color code size for searching displays of different density. Human Factors, 18, 273-280.

Christ, R. E. (1975). Review and analysis of color coding research for visual displays. Human Factors, 17, 542-570.

Donner, K. A., McKay, T., O'Brien, K. M., & Rudisill, M. (1991). Display format and highlighting validity effects on search performance using complex visual displays. Proceedings of the Human Factors Society 35th Annual Meeting (pp. 374-378). Santa Monica, CA: Human Factors Society.

Fisher, D. L., Coury, B. G., & Tengs, T. O. (1985). Optimizing the set of highlighted options on video display terminal menus. Proceedings of the Human Factors Society 29th Annual Meeting (pp. 650-653). Santa Monica, CA: Human Factors Society.

Fisher, D. L., Coury, B. G., Tengs, T. O., & Duffy, S. A. (1989). Minimizing the time to search visual displays: The role of highlighting. Human Factors, 31, 167-182.

Fisher, D. L., & Tan, K. C. (1989). Visual displays: The highlighting paradox. Human Factors, 31, 17-30.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. Journal of Experimental Psychology: Human Perception and Performance, 18, 1030-1044.

Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. Journal of Experimental Psychology: Human Perception and Performance, 20, 317-329.

Johnson, W.W., Battiste, V., Delzell, S., Holland, S., Belcher, S., & Jordan, K. (1997). Development and Demonstration of a Prototype Free Flight Cockpit Display of Traffic Information. In the Proceedings of the 1997 SAE/AIAA World Aviation Congress (paper 975554). New York: American Institute of Aeronautics and Astronautics.

Kopala, C. G. (1979). The use of color-coded symbols in a highly dense situation display. Proceedings of the Human Factors Society 23rd Annual Meeting (pp. 397-401). Santa Monica, CA: Human Factors Society.

Lit, A., Young, R. H., & Shaffer, M. (1971). Simple time reaction as a function of luminance for various wavelengths. Perception and Psychophysics, 10, 397-399.

Luder, C. B., & Barber, P. J. (1984). Redundant color coding on airborne CRT displays. Human Factors, 26, 19-32.

MacDonald, W. A., & Cole, B. L. (1988). Evaluating the role of colour in a flight information cockpit display. Ergonomics, 31, 13-37.

Markowitz, J. (1971). Optimal flash rate and duty cycle for flashing visual indicators. Human Factors, 13, 427-433.

Martens, M. H., & Wickens, C. D. (1995). Lowlighting solutions to display clutter. University of Illinois Institute of Aviation Technical Report (ARL-95-10/NASA-95-4). Savoy, IL: Aviation Research Laboratory.

Mish, F. C. (Ed.). (1988). Webster's Ninth New Collegiate Dictionary (9th ed.). Springfield, MA: Merriam-Webster.

Perlman, G., & Swan, J. E. (1994). Relative effects of color, texture, and density coding on visual search performance and subjective preference. Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting (pp. 235-239). Santa Monica, CA: Human Factors and Ergonomics Society.

Philipsen, G. (1994). Effects of six different highlighting modes on visual search performance in menu options. International Journal of Human-Computer Interaction, 6, 319-334.

Preece, J., Rogers, Y., Sharp, H., Benyon, D., Holland, S., & Carey, T. (1994). Perception and representation. In S. Plumtree (Ed.), Human-Computer Interaction (p. 93). Harlow, England: Addison-Wesley

Proctor, R. W., & Van Zandt (1994). Attention and the assessment of mental workload. In S. Badger & L. Pearson (Eds.), Human factors in simple and complex systems (pp. 186-209). Boston: Allyn and Bacon.

Remington, R. W., Johnston, J. C., & Yantis, S. (1992). Involuntary attentional capture by abrupt onsets. Perception & Psychophysics, 51, 279-290.

Smith, S. L., & Goodwin, N. C. (1971). Blink coding for information display. Human Factors, 13, 283-290.

Smith, S. L., & Goodwin, N. C. (1972). Another look at blinking displays. Human Factors, 14, 345-347.

Spoto, C. G., & Babu, A. J. G. (1989). Highlighting in alphanumeric displays: The efficacy of monochrome methods. Proceedings of the Human Factors Society 33rd Annual Meeting (pp. 370-374). Santa Monica, CA: Human Factors Society.

Tan, K. C., & Fisher, D. L. (1987). Highlighting and search strategy considerations in computer-generated displays. Proceedings of the Human Factors Society 31st Annual Meeting (pp. 524-528). Santa Monica, CA: Human Factors Society.

Thackray, R. L., & Touchstone, R. M. (1991). Effects of monitoring under high and low taskload on detection of flashing and coloured radar targets. Ergonomics, 34, 1065-1081.

Theeuwes, J. (1994). Stimulus-driven attentional capture and attentional set: Selective search for color and visual abrupt onsets. Journal of Experimental Psychology: Human Perception and Performance, 20, 799-806.

Treisman, A. (1986). Features and objects in visual processing. Scientific American, 254, 114-126.

Treisman, A. (1992). Representing visual objects. In D. Meyer & S. Kornblum (Eds.), Attention and Performance XIV (pp. 163-175). Hillsdale, NJ: Lawrence Erlbaum.

Treisman, A. (1993). The perception of features and objects. In A. Baddley & L. Weiskrantz (Eds.), Attention: Selection, Awareness, and Control: A tribute to Donald Broadbent (pp. 5-35). New York: Clarendon Press.

Treisman, A., Kahneman, D., & Burkell, J. (1983). Perceptual objects and the cost of filtering. Perception & Psychophysics, 33, 527-532.

Treisman, A., & Souther, J. (1985). Search asymmetry: A diagnostic for preattentive processing of separable features. Journal of Experimental Psychology: General, 114, 285-309.

Van Orden, K. F., Divita, J., & Shim, M. J. (1993). Redundant use of luminance and flashing with shape and color as highlighting codes in symbolic displays. Human Factors, 35, 195-204.

Wickens, C. D. (1992). Attention in perception and display space. In L. Pearson & M. Caterer (Eds.), Engineering psychology and human performance (2nd Ed.) (p. 95). New York: Harper Collins Publishers.

Wickens, C. D., & Andre, A. D. (1990). Proximity compatibility and information display: Effects of color, space, and objectness on information integration. Human Factors, 32, 61-77.

Wickens, C. D. & Yeh, M. (1997). Attentional filtering and decluttering techniques in battlefield map interpretation. Proceedings of the Advanced Displays and Interactive Displays Federated Laboratory First Annual Symposium (2-35 - 2-42). Adelphi, MD: Army Research Laboratory.

Yantis, S. (1993). Stimulus-driven attentional capture and attentional control settings. Journal of Experimental Psychology: Human Perception and Performance, 19, 676-681.

Appendix

HSIRB Approval

San José State
UNIVERSITY

Office of the Academic Vice President
Associate Vice President Graduate Studies and Research
One Washington Square
San José, CA 95192-0025
Voice 408-924-2480
Fax 408-924-2477
E-mail gstudies@wahoo.sjsu.edu
http://www.sjsu.edu

TO: Stephen Tse
815 35th Ave.
San Francisco, CA 94121

FROM: Nabil Ibrahim,
Acting AVP, Graduate Studies & Research

DATE: March 4, 1999

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"The Effects of Highlighting Modes on Engagement and Disengagement of Visual Search"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Nabil Ibrahim, Ph.D., immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480