Tim Halverson
DRP paper
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The Influence of Local Density and Link Color on Visual Search

Visual search in an important part of human-computer interaction (HCI) research (Byrne, 1993; Czerwinski, Tan, & Robertson, 2002; Jacob & Karn, 2003). It is through visual search that most people locate the content and controls for many computer tasks. Yet, it is not well understood how visual search is applied with the use of computers for a great many visual tasks.

HCI needs a good, unified theory of visual search. In application and web interface design, practitioners must often rely on intuition, or on guidelines that have little or no empirical support (such as Mullet & Sano, 1995; National Cancer Institute, 2002, for many examples). A good applied theory of visual search may help verify some guidelines for visual layout, or disambiguate seemingly contradictory guidelines. A large body of basic research on visual search exists in psychology (such as Bertera & Rayner, 2000; Greene & Rayner, 2001; Hayhoe, Lachter, & Moeller, 1992; Shen, Reingold, & Pomplun, 2000; Treisman, 1998). Many phenomena have been observed and many theories have been proposed to explain them.

Previous HCI research has investigated the extent to which theories from basic research apply to more ecologically valid tasks in HCI. On such line of research investigated the visual search of "two-dimensional" hierarchical layouts with experimentation and cognitive modeling (Hornof, 2001, in press; Hornof & Halverson, 2003). In these experiments, participants searched for a precued target item in labeled or unlabeled layouts. In the labeled layouts, groups had headings and the participant was precued with the target group heading as well as the target item. In the unlabeled layouts, the groups had no headings. It was found that a useful visual hierarchy motivated fundamentally different search strategies. That is, when useful group headings are present, people will first search the headings and then the group content.

These studies are a significant step in providing empirical support for the cognitive, perceptual and motor processes involved in the visual search of hierarchical layouts and exploring basic research on visual search in an applied setting. However, these studies are only the beginning of determining how two-dimensional menus, and menu-like layouts, are visually searched, and how basic research can be applied. Further work is required with the many variations in stimuli and tasks that can occur in such layouts, such as seen on the web.

The current study extends the work in Hornof (2001) and Hornof and Halverson (Hornof & Halverson, 2003) by investigating the visual search of more complex non-hierarchical layouts. Specifically, the study examines the effects local density and text color. The purpose of this research is to (1) further inform the development of a predictive tool for evaluation of visual layouts, (2) contribute to the theories of applied visual search in human-computer interaction, (3) provide empirical support for design guidelines, and (4) determine where more thorough investigation is required.

Interaction Between Display Density and Effective Field of View

The effective field of view (EFV), also referred to as the useful field of view or perceptual span, is the region from which the visual perceptual system processes information in a single fixation. There have been many studies on EFV for various tasks (Bertera & Rayner, 2000; Greene & Rayner, 2001; Mackworth, 1976; Ohashi & Kiyonobu, 1997; Rayner & Fisher, 1987; Reingold, Charness, Pomplun, & Stampe, 2001). These studies have found a limited region in the visual field that is sufficient for normal perception of static scenes. This region can be centered on the point of fixation or can be asymmetric with respect to the point of fixation. In addition, these studies have found that the EFV varies in size by type of stimuli, type of task, and task difficulty.

The density of items in a display is one factor that has been shown in EFV studies to affect how many items can be perceived in a single fixation (Bertera & Rayner, 2000; Mackworth, 1976). Bertera and Rayner varied the density of randomly placed characters between trials in a search task and found that search time decreased as the density increased. Mackworth showed similar results in a study in which participants searched for a square among uniformly distributed circles on a scrolling vertical strip.

A study by Ojanpää, Näsänen, and Kojo (2002) studied the effective field of view in word lists. One factor they varied was line spacing, which is one property that can affect density. They found that as the vertical spacing between words increased (i.e. as density decreased), search time also increased. This is consistent with the previous research. However, a closer look at the data of Ojanpää, et al. reveals that search time did not start to increase until the distance between centers of words increased beyond 1.5 degrees of visual angle.

Density may be measured as *overall density* or *local density*. Overall density is simply the number of items divided by the area occupied by all items. Local density is the number of items in a given region divided by the area of that region.

Besides affecting the number of items inspected per fixation, local density may also affect the *order* of inspection. Several studies have found that visual attention is drawn to "more informative" stimuli (for example, Berlyne, 1958; Mackworth & Morandi, 1967). More informative is often defined as regions having greater contour in pictorial stimuli. For example, with geometric shapes, angles are considered more informative than straight lines. Yet, it is not readily known how to predict *a priori* which of two arbitrary stimuli are more informative. One plausible factor of "informativeness" is local density. It may be that regions with a higher local density are more informative, and thus will be more likely to draw attention.

The following hypotheses will be tested in this study:

H1: The search time per word is greater in sparse layouts than in dense layouts.

H2: Dense regions will be searched before sparse regions.

The above hypotheses build on previous research by investigating the extent to which previous findings hold in tasks that are more ecologically valid than those used in Bertera and Rayner (2000) and Mackworth (1976) . While these previous studies are informative, the stimuli are single characters or simple shapes. It is unclear whether the same phenomena will be seen with stimuli in which the items are more complex, such as words, or when density changes within a visual layout. Figure 1 shows an example of a web page in which local density varies in different regions.

Text Color

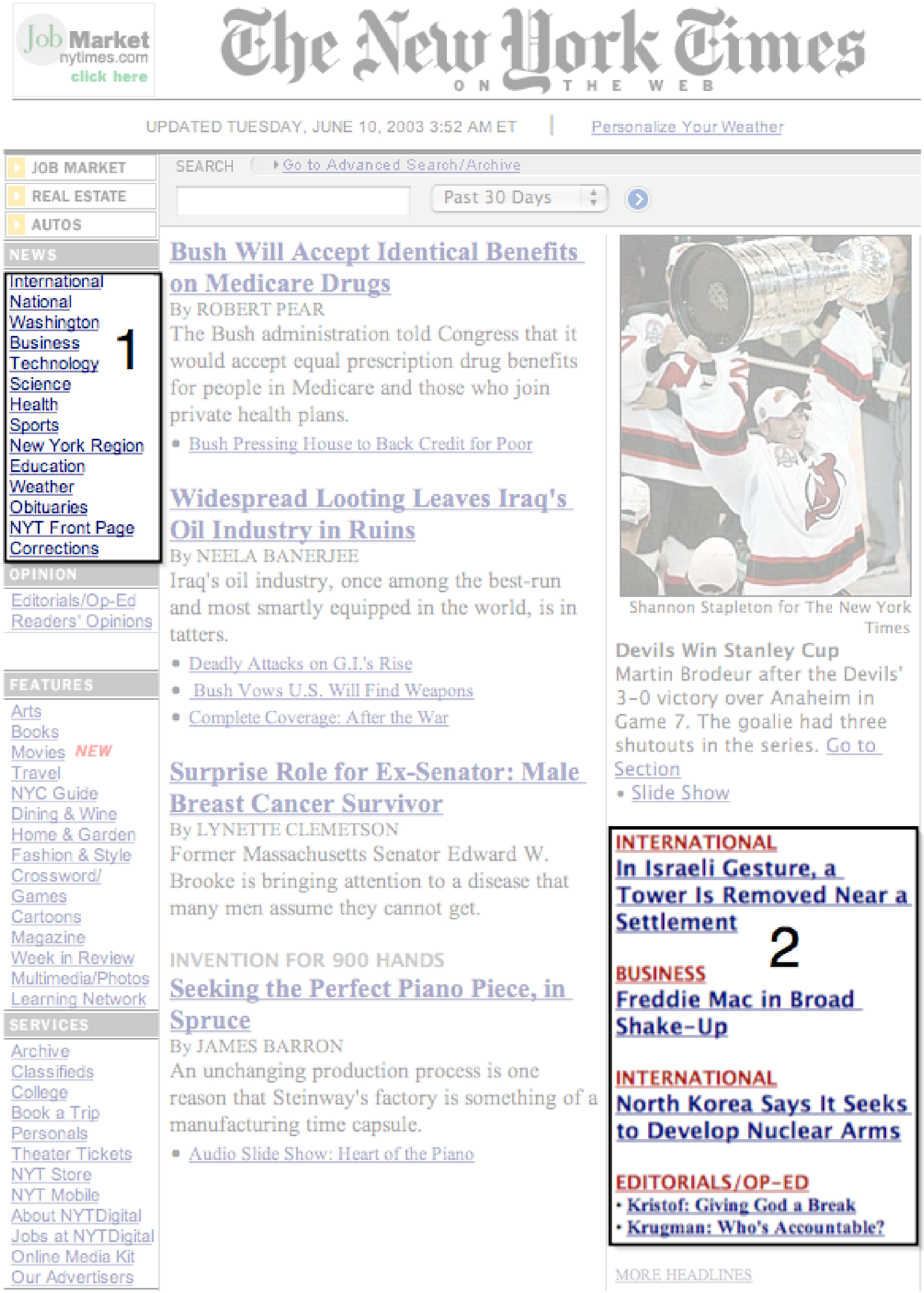
The effect of color on visual search has been investigated in a number of studies (see Christ, 1975, for an early review). In general, it has been found that locating targets distinguished by color is significantly faster than locating targets distinguished by a conjunction of two or more features. A phenomenon that helps explain this faster search time with color is the “pop-out” effect. The “pop-out” effect, first studied by Julesz (1981) and later integrated into Treisman’s feature integration theory (see Treisman, 1998, for a review), is the phenomenon in which targets distinguished by a basic visual feature, like color, curvature, or orientation, can be found in roughly constant time, independent of the number of distractors.

Further research has found that people can selectively attend to items of a target color among distracters of different colors, but that the this ability is task-dependent (Brawn & Snowden, 1999). In addition, Shih and Sperling (1996) found that selectively attending to a color in a rapid serial visual presentation (RSVP) task guides visual search spatially, but does not exclude unattended colors from perception. These studies suggest that when searching for a target among two distinct colors, people may be able to selectively attend to one color, but that some interference may be caused by the items of the second color. A real-world example might be a user searching a web page for a particular blue (unvisited) link while ignoring the magenta (visited) links. It is this sort of scenario that has motivated web design guidelines for link coloring (National Cancer Institute, 2002). While observational studies support the consistent differentiation of visited and unvisited link with color, limited empirical evidence is provided to support such guidelines.

The following hypotheses will be tested in this study:

H3: When visually searching for a target word of known color among words of the same color and a distinct distractor color, the search time increases with the number of target-colored items.

H4: Visual search for a target of a known color is faster among distractors of one color than among distractors of two distinct colors.



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By ROBERT PEAR

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- Complete Coverage: After the War

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INVENTION FOR 900 HANDS

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By JAMES BARRON

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- Audio Slide Show: Heart of the Piano

Shannon Stapleton for The New York Times

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- Slide Show

INTERNATIONAL

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EDITORIALS/OP-ED

- **Kristof: Giving God a Break**
- **Krugman: Who's Accountable?**

Figure 1. A section of the NYTimes.com home page. The two labeled sections demonstrate a difference in local-density. Region 1 is a dense group with respect to Region 2. (Source: http://www.nytimes.com/ June 2, 2003)

Experiment 1: Local Density

As seen in Figure 1, web pages incorporate a variety of text densities. This first experiment investigates the effect of varying density on visual search. In Experiment 1, one spatial property – local density – was manipulated. Local density is defined here as the number of potential targets per degree of visual angle within a visually distinct group. This experiment investigated the effect of local density, and the mixing of local densities, in visual search of structured layouts where the stimuli were words.

Method

Participants. Twenty-four people, 10 female and 14 male, ranging in age from 18 to 55 years of age (mean = 24.5) from the University of Oregon and surrounding communities participated in the experiment. The participants were screened as follows: 18 years of age and older; experienced using graphical user interfaces (such as Microsoft Windows or Macintosh); no learning disability; normal use of both hands; and normal or corrected-to-normal vision. Participants were paid \$10, plus a bonus that ranged from \$0 to \$4.54 based on their performance.

Twenty-two of these participants also participated in Experiment 2. When this was the case, the order of the two experiments was counterbalanced and the base of pay of \$10 was for both experiments.

Apparatus. Visual stimuli were presented on a ViewSonic VE170 LCD display set to 1280 by 1024 resolution at a distance of 61 cm that resulted in 40 pixels per degree of visual angle. The experimental software ran on a 733Mhz Apple Power Macintosh G4 running OS X 10.2.6. The mouse was an Apple optical Pro Mouse, and the mouse tracking speed was set to the fourth highest in the mouse control panel.

Eye movements were recorded using an LC Technologies Eyegaze System, a 60 Hz pupil-center/corneal-reflection eye tracker. A chinrest was used to maintain a consistent eye-to-screen distance.

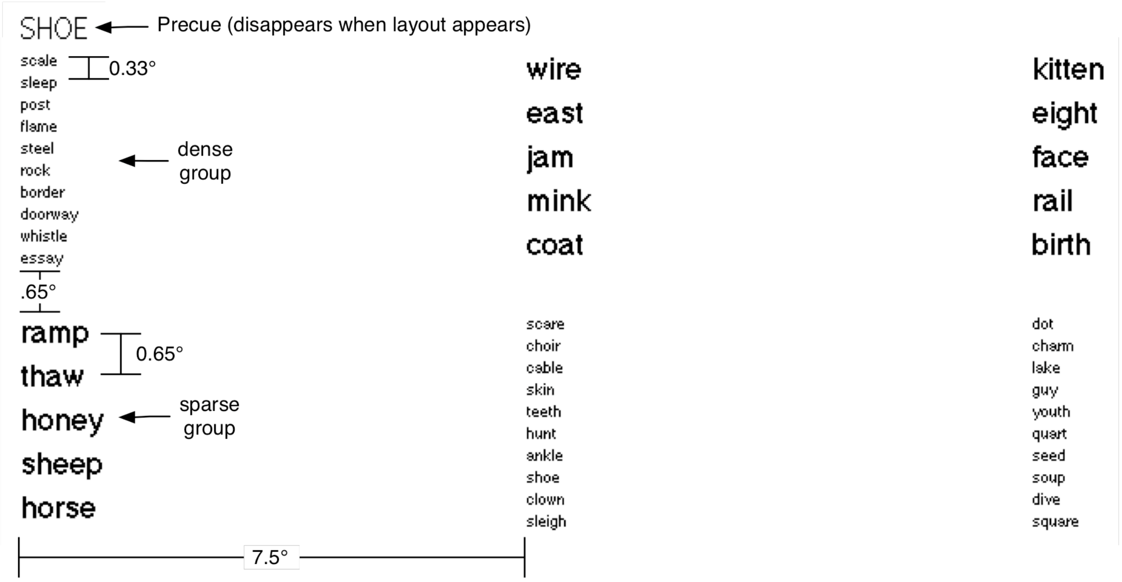

Figure 2. A mixed-density layout. All angle measurements are in degrees of visual angle.

Stimuli. Figure 2 shows a sample layout from one mixed-density trial. All trials contained six groups of left-justified, vertically-listed black words on a white background. The groups were arranged in three columns and two rows. Columns were 7.5 degrees of visual angle from left edge to left edge. Rows were separated by .65 degrees of visual angle.

As shown in Figure 2, there were two types of groups with different local densities: *Sparse* groups contained five words of 18 point Helvetica font with 0.65 degrees of vertical angle between the centers of adjacent words (0.45° for word height, and 0.2° for blank space). *Dense* groups contained 10 words of 9 point Helvetica font with 0.33 degrees of vertical angle between the centers of adjacent words (0.23° for word height, and 0.1° for blank space). Hence, both groups subtended the same vertical visual angle.

There were three types of layouts: *sparse*, *dense*, and *mixed-density*. Sparse layouts contained six sparse groups. Dense layouts contained six dense groups. Mixed-density layouts contained three sparse groups and three dense groups. The arrangement of the groups in the mixed-density layouts was randomly determined for each trial. Figure 2 shows an example of the mixed-density layout. Sparse and dense layouts were identical to the mixed-density layout, with the exception of group densities.

This experiment was designed, in part, to determine the effect of combining multiple local densities in a single layout. Combining multiple local densities necessitated maintaining the number, size (in degrees of visual angle), and spacing of groups between layouts. Therefore, text size and number of words per group were varied to produce different local densities, which was not seen as a problem since text size and number of words often covary with local density in real-world tasks.

The words used in each trial were selected randomly from a list of 765 nouns generated from the MRC Psycholinguistic Database (Wilson, 1988). No word appeared more than once per trial. The words in the list were selected as follows: three to eight letters, two to four phonemes, above-average printed familiarity, and above-average imagability. Five names of colors and thirteen emotionally charged words were removed.

The target word was randomly chosen from the list of words used for each trial. The participant was precued with the target word before each layout appeared. The precue appeared at the same location every time, directly above the top left word in the layout, in 14 point Geneva font.

Procedure. Each trial proceeded as follows: The participant was precued with a target word, clicked on the precue, found the target word, moved the cursor to the target word, and clicked on it.

The trials were blocked by layout type. Each block contained 30 trials, preceded by five practice trials. The blocks were fully counterbalanced.

At the start of each experiment, the eye tracker was calibrated to the user. The calibration procedure required the participant to fixate a series of nine points until the average error between the predicted point of gaze and the actual location of the points fell below an error threshold (approximately 63.5 mm). During the execution of the experiment, an objective measure of the eye tracker's calibration was taken during each trial as described in Hornof and Halverson (2002). If the calibration had deteriorated below a threshold (approximately 1.27 cm), a calibration was automatically initiated before the next trial. In addition, the trial in which the error was found was not analyzed, and a new trial was added to the block.

To separate visual search time from mouse pointing time, the point completion deadline was used (Hornof, 2001). In short, participants were instructed to not move the mouse until the target was found. Once the mouse was moved more than five pixels in any direction, they had a small amount of time (determined by Fitts' law) to click on the target. If this time was exceeded, a buzzer sounded and the trial was recorded as an error. The trial in which the error occurred was not analyzed, and a new trial was added to the block.

Results

The primary measures of interest were the search time per trial and search time per word. Table 1 shows the mean search time for each layout type, before and after normalizing for the number of words per layout. An alpha level of .05 was used for all statistical tests.

Table 1. Search time per trial and search time per word for sparse, mixed-density, and dense layouts.

	Search time per		Search time per	
Layout	Mean	SD	Mean	SD
Sparse	3,125	666	104	22
Mixed-Density	5,753	1,493	128	33
Dense	7,925	1,892	132	32

n = 24

The mean search time for each of the twenty-four participants was analyzed using a repeated-measures MANOVA. Participants searched layouts with fewer dense groups faster than layouts with more dense groups, F(2,22) = 98, p < .0001. Since more dense layouts had more words to search, the analysis was also run normalizing for the number of words per layout. A repeated-measures MANOVA was performed on the search time divided by the number of words in the layout. This measure assumes that on average participants inspected the same proportion of words, relative to the total number of words, in each layout. Participants spent, on average, less time-per-word in layouts with fewer dense groups, F(2,22) = 11, p = .0004. This difference was significant between the sparse and the mixed layouts (HSD = -23.677, p < .05); and between the sparse and dense layouts (HSD = -27.912, p < .05); but not significant between the mixed and dense layouts (HSD = -4.235, p > .05).

The search time per trial was analyzed with a repeated-measures 2×2ANOVA: layout uniformity (all one density vs. mixed density) and target group density (sparse vs. dense). Figure 3 shows the results graphically. Locating targets in dense groups took longer than in sparse groups, F(1, 23) = 84, p < .0001. The mean search time for uniform-density layouts (all sparse and all dense) was no different than the mean search time for mixed-density layouts, F(1,23) = 1, p = .3213. However, there was an interaction between layout uniformity and target group density, F(1,23) = 17, p = .0004. In other words, when the target was in a sparse group, participants found the target faster in uniform-density layouts (all dense and all spare) than in mixed layouts; when the target was in a dense group, participants found the target faster in mixed-density layouts.

Further, in the mixed density layout, participants found the target faster when it was in a sparse group, F(1,23) = 30, p < .0001.

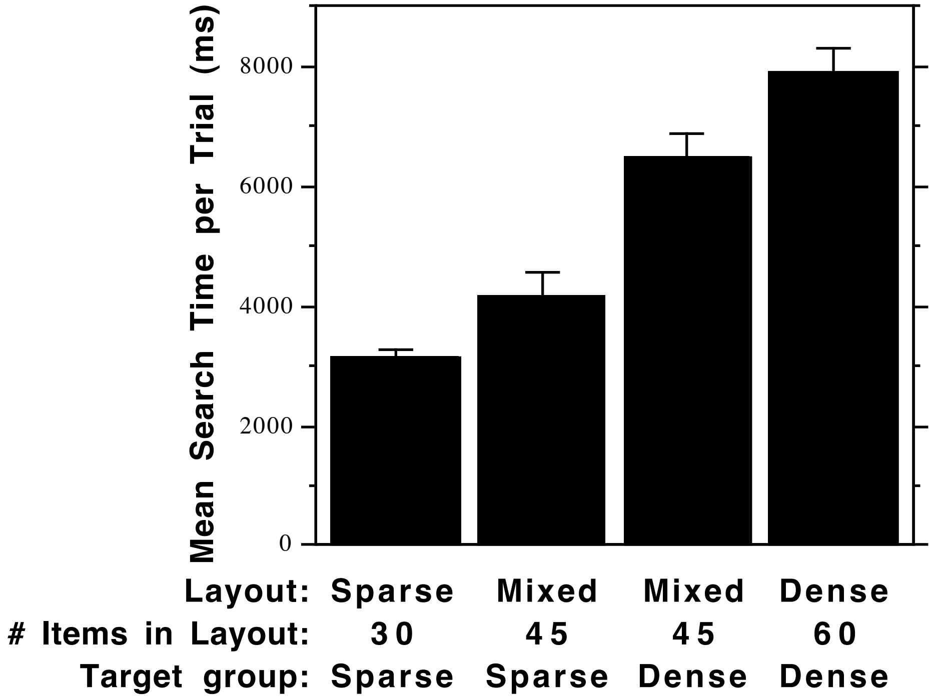

Figure 3. Search time for trials in which the layout was sparse, mixed-density, or dense, and the target was in either a sparse or dense group. Error bars indicate ±1 standard error.

<u>Discussion</u>

This experiment investigated the effect of local density, and the mixing of local densities, on visual search of structured layouts. The results from the current study are inconsistent with other research on the effect of density on visual search. The current study shows a case in which the search time per item increases as a function of density, whereas other studies found that search time decreases (Bertera & Rayner, 2000; Mackworth, 1976). However, the differences may be explained by studying the differences in the tasks. For example, the stimuli in this study were words, Bertera and Rayner used single characters and Mackworth used simple shapes. In addition, the layouts in the current study were structured, whereas Bertera and Rayner used random layouts.

A significant increase in search time was found as the number of dense groups increased. This is not surprising because the number of words per layout also increased, and distractor numerosity is in general highly correlated with search time.

When the search time was normalized for the number of words per layout, a significant difference in the mean search time per item was still found. These data are counter to the study's first hypothesis – that the search time per word is greater for sparse layouts than for dense layouts. People actually spent *less* time per word searching sparse layouts. This result is contrary to the search time results found by Bertera and Rayner (2000) in which the search time decreased as the density of a constant number of items increased. This current studies finding may have resulted from too much "clutter" in the dense groups. A more thorough study is needed to determine the trend seen in this data holds for intermediate densities.

The data is also counter to this study's second hypothesis – that participants will search dense groups first. A preference for search order as a function of group density was found. However, it was in the opposite direction than predicted. The results show that when the target was in a sparse group the mean search time was much closer to that of the sparse layouts, and that when the target was in a dense group the mean search time was much closer to that of the dense layouts. We assume a serial, self-terminating search, without replacement, across all three layouts. If the participants had not favored one density over the other, then the mean search time in the mixed-density layouts would not have varied as a function of the density of the target group. However, this is not what we observed. On the other hand, if one density were consistently searched before the other, then we would expect the search time for targets located in groups of a preferred density to be lower than the search time for targets located in the other groups, which is what we observed. The data suggest that the participants tended to search the sparse groups first. Figure 4 helps to illustrate this point.

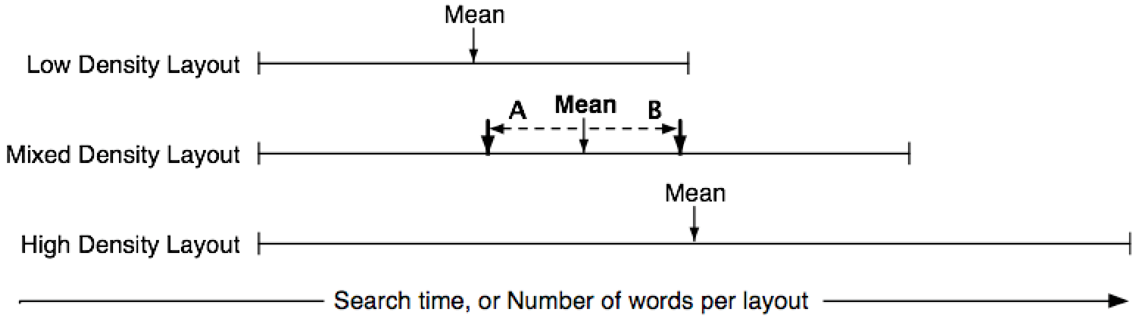

Figure 4. Hypothetical search time. As the number of items increase, the search time increases proportionately. The "central" means indicate the hypothetical mean for a random, serial, self-terminating search in a layout with a single target. The dashed line A represents the shift of the mean search time for trials in which the target appears in a subset of groups that are usually searched first. The dashed line B represents the shift of the mean search time for trials in which the target appears in a subset of groups that are usually searched last. The observed search times are consistent with A when the target is in a sparse group, and with B when the target is in a dense group. Hence, the data suggests participants searched sparse groups first.

Implications for design. The finding that sparse groups tend to be searched earlier than dense groups supports design guidelines on density (Mullet & Sano, 1995). Since people tend to search sparse groups before dense groups, this suggests that information essential for the primary goals a visual layout needs to support should be placed in sparse groups relative the other information in the layout. The sparse groups will tend to attract the users' attention first, and therefore the users will be more likely process the important information earlier than less important information.

Experiment 2: Link Color

In the first experiment investigated the effect of varying text density, a common design element seen in web pages. This second experiment investigates the effect of varying text color. Varying hypertext link color is another common web design technique: “unvisited” links are colored differently than “visited” links. The idea is that users can focus their search on just “unvisited” links to increase the efficiency of search for some tasks. This experiment investigated visual search of structured layouts where only a subset of text, based on the color of text, need be searched.

Method

Participants. Twenty-four people, 11 female and 13 male, ranging in age from 19 to 55 years of age (mean = 25.1) from the University of Oregon and surrounding communities participated. The participants were screened as in Experiment 1, and were also tested for normal color vision. Participants were paid $10, plus a bonus that ranged from $2.53 to $9.20 based on their performance.

Apparatus. The apparatus was the same as in experiment 1.

Stimuli. The spatial properties of the stimuli were identical to those in Experiment 1, except that all groups were sparse. The text color differed from Experiment 1 – all distractors were either blue or red. The target word and precue were always blue. Red-green-blue saturation percentages were 0-0-67 for blue and 67-0-0 for red.

Figures 5 and 6 show two layouts used in the experiment. All participants searched seven types of layouts: One layout contained 30 blue words, two layouts contained 20 blue words, two layouts contained 10 blue words, and two layouts contained 1 blue word. In the pairs of layouts with the same number of blue words, all non-blue positions were filled with red words in one layout and left blank in a second “complementary” layout.

Each trial in a complementary layout had a “matched” trial in the other layout with the same number of blue words. These two trials put the blue words in the same position, including the target position, but the selection of words was independent. The layout shown in Figure 5, for example, appeared again in a complementary layout with different blue words in the same positions, and with all red words removed. Figure 6 shows this complementary layout.

Figure 5. Layout with 10 blue words (drawn here as black), and with red words present. All angle measurements are in degrees of visual angle.

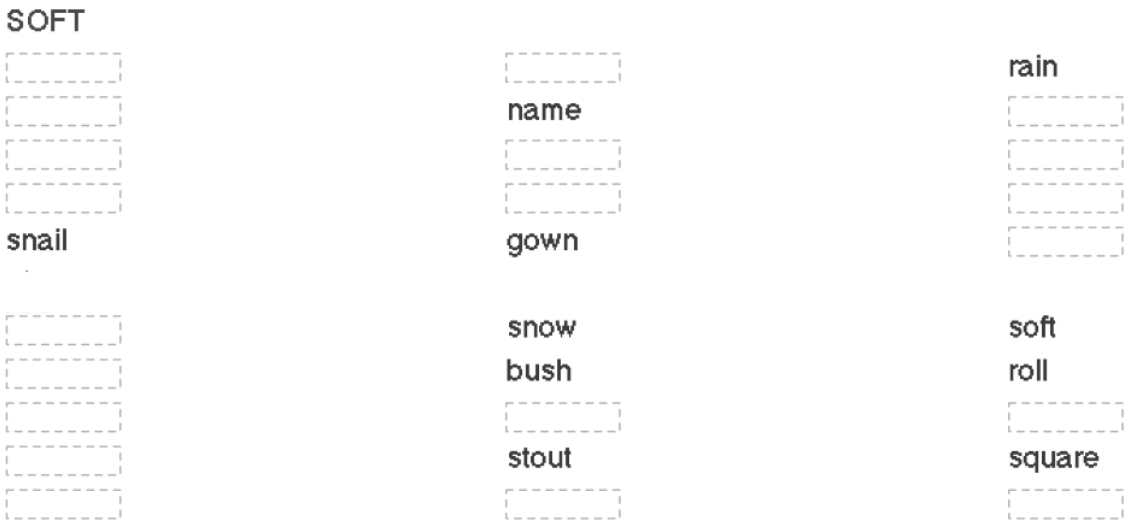

Figure 6. Layout with 10 blue words, and with no red words. Blank locations are indicated by the dashed rectangles, which did not appear in the layout. This layout is "matched" to that shown in Figure 5 in that the blue words appear in the same locations.

Procedure. The procedure was the same as in Experiment 1, with the following exceptions: The blocks were counterbalanced using the balanced Latin square technique. Participants were informed verbally and in written instructions that the target would always be blue.

Results

The primary measures of interest were the search time per trial and search time per blue word. Table 2 shows the mean search time for each layout type, before and after normalizing for the number of blue words per layout. An alpha level of .05 was used for all statistical tests.

Table 2. Search time per trial and search time per blue word for all layouts

		Search time per trial		Search time per	
Red words present	Number of blue words	Mean	SD	Mean	SD
Yes	1	393	69	393	69
	10	1,657	329	166	33
	20	2,488	457	124	23
	30	3,005	544	100	18
No	1	289	46	289	46
	10	1,387	187	139	19
	20	2,191	273	110	14
	30	3,005	544	100	18

n = 24

The search time was analyzed using a repeated-measures MANOVA. Figure 7 shows the results graphically. Participants found the target faster in layouts with fewer blue words than in layouts with more blue words, $F(3,21) = 379$, $p < .0001$. Participants also searched identically-configured layouts faster when the red distractors were absent, $F(1,23) = 32$, $p < .0001$. Furthermore, there is an interaction between the number of blue distractors and the presence of red distractors, $F(3,21) = 23$, $p < .0001$; in other words, the presence of red words slowed search more when there were fewer blue words present.

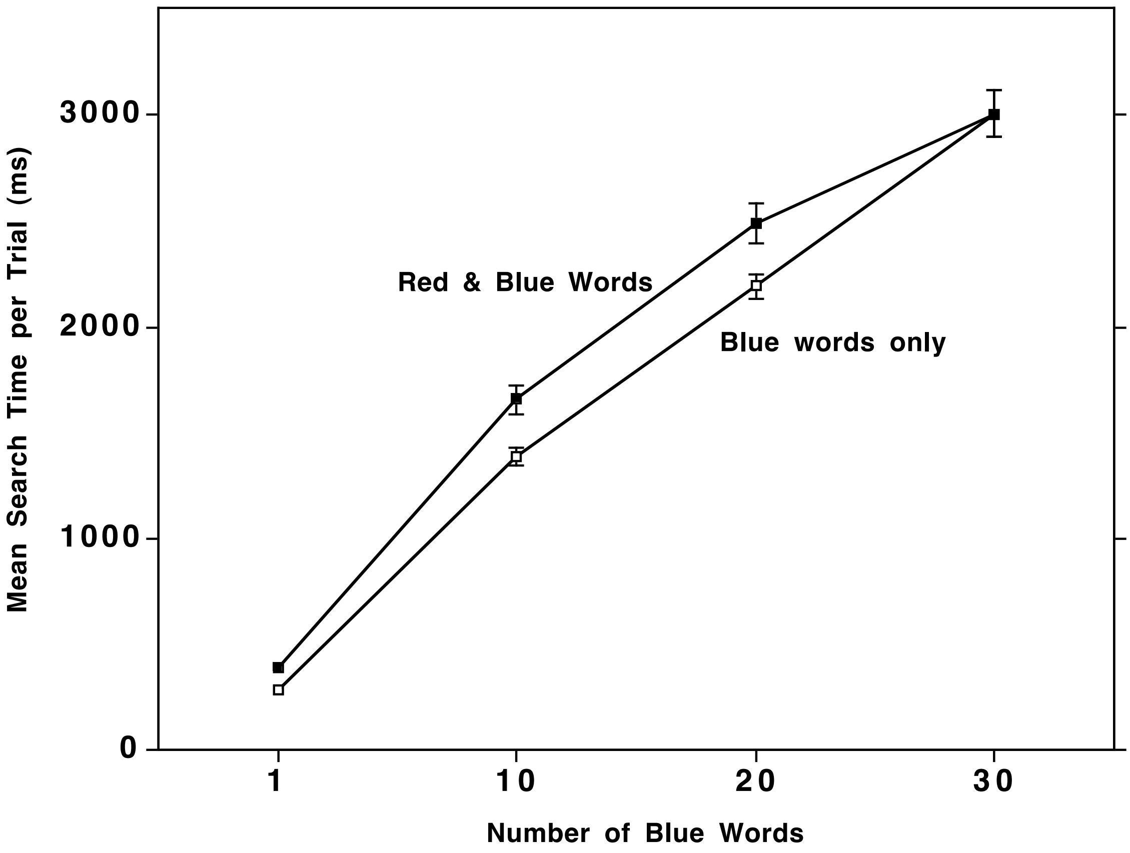

Figure 7. Mean search time per trial as a function of the number of blue words. Error bars indicate ±1 standard error, where they are large enough to be seen.

Normalizing for the number of blue words per layout, a repeated-measures MANOVA was performed. Figure 8 shows the results graphically. Participants spent less time searching (per blue word) in layouts with more blue words, $F(3,21) = 187$, $p < .0001$. Participants also spent less time searching when red distractors were absent, $F(1,23) = 69$, $p < .0001$. Moreover, there is an interaction between the number of blue distractors and the presence of red distractors, $F(3,21) = 23$, $p < .0001$. The interaction can be seen in Figure 8 in the narrowing of the gap between the two lines – the presence of red words slowed the search more when there were fewer blue words present.

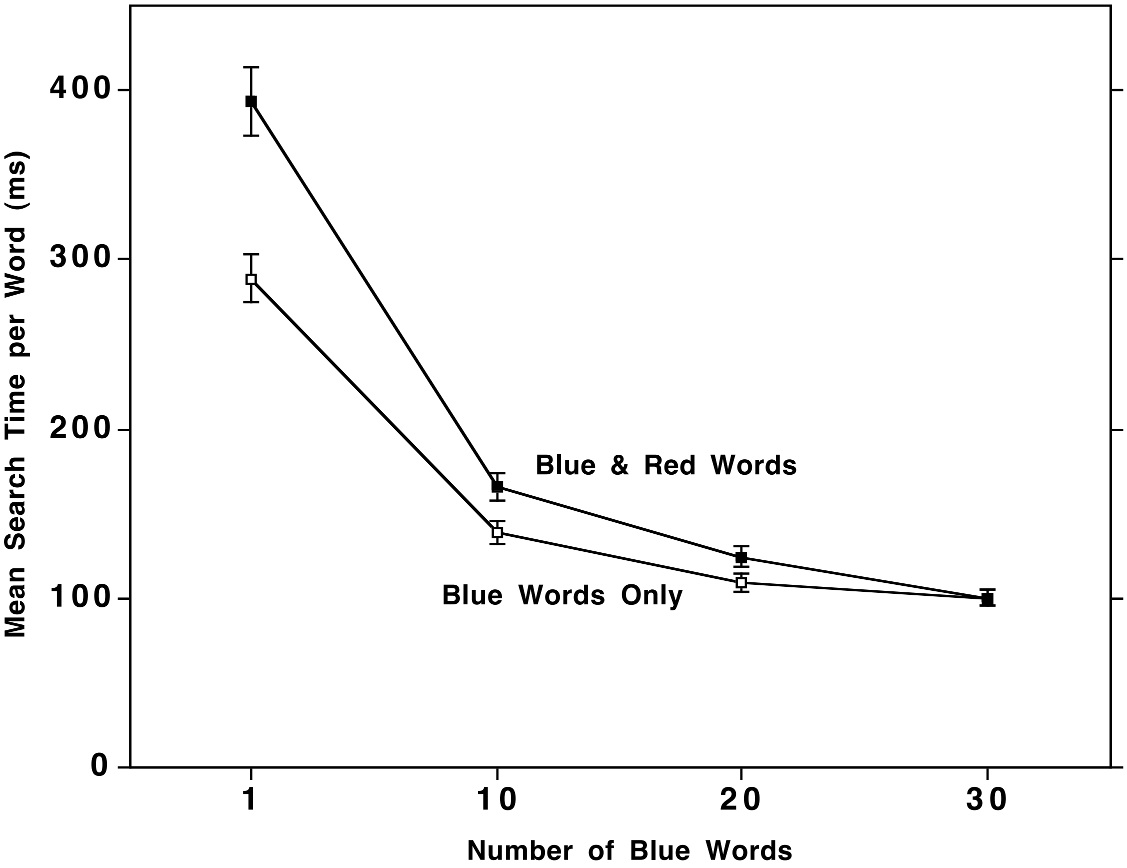

Figure 8. Mean search time per word as a function of the number of blue words. Error bars indicate ±1 standard error.

The initially dramatic downward slope in Figure 8 is possibly due, in part, to some constant, per trial reaction time "cost" that was lessened for trials in which blue words appeared when the reaction time was normalized for the number of blue words. Therefore, the search time per word was adjusted for hypothetical *startup cost* (e.g. responding to layout onset) or *finishing costs* (e.g. verifying that the target word had been found). These costs were approximated by the total search time for the trials in which one blue word appeared (289 ms for layouts without red words and 393 ms for those trials with red words). The start-up and finishing costs were subtracted form the search time per trial before normalizing for the number of blue words. The results are shown in Figure 9. All of the effects remained. Participants spent less time searching (per blue word) in layouts with more blue words, F(2, 22) = 25, p < .0001, participants spent less time searching when red distractors were absent, F(1, 23) = 10, p = .0052, and the same interaction was present, F(2, 22) = 5, p = .0115.

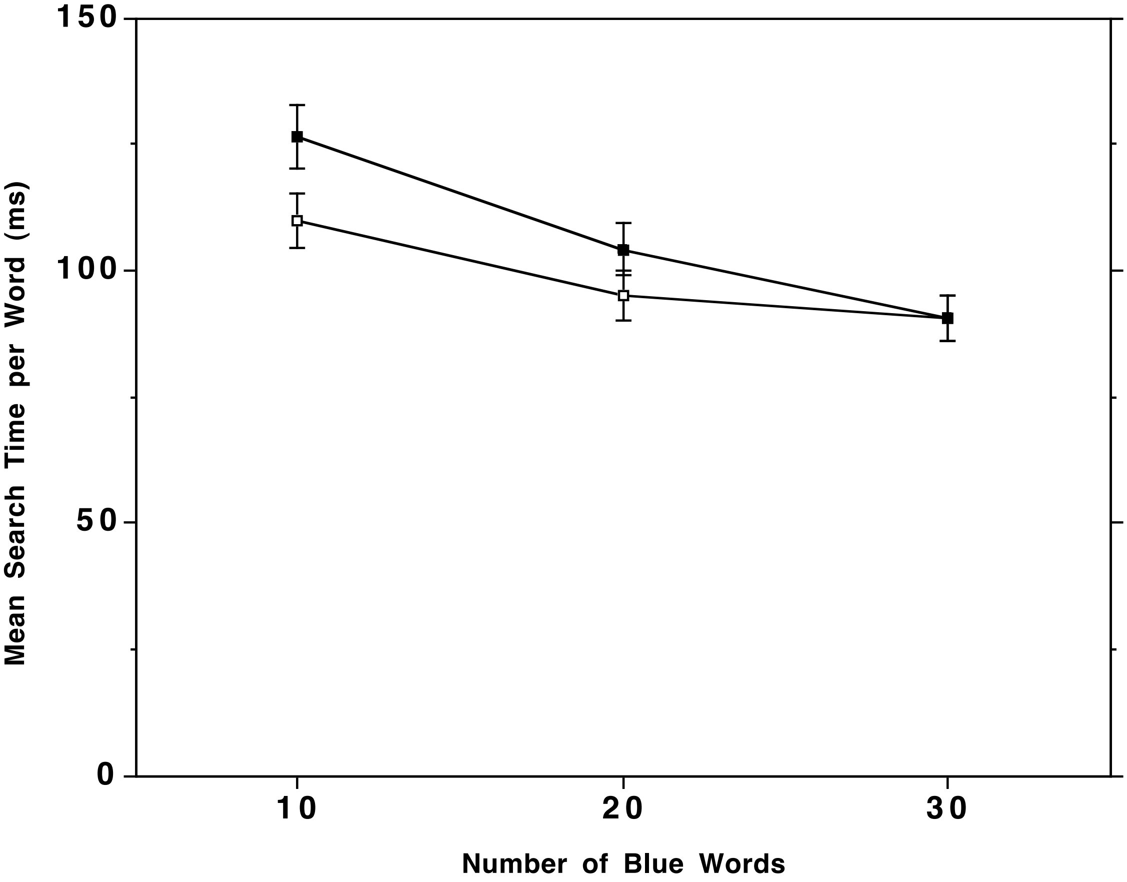

Figure 9. Mean search time per word, after startup and finishing costs were subtracted, as a function of the number of blue words. Error bars indicate ±1 standard error.

Discussion

This experiment investigated the visual search of words of two distinct colors when the color of the target is always known. The results are consistent with other related research. In addition, an interesting trend was found in which the presence of words of a second color (red) slowed search more when fewer words of the target color (blue) were present.

Search time increased as the ratio of blue to red words increased. This supports this study's third hypothesis – when searching for a target word of a known color among words of the same color and a second distinct color, the search time will increase as a function of the number of target-colored items. These results are similar to other research on conjunctive visual search (Poisson & Wilkinson, 1992; Shen, Reingold, & Pomplun, 2003; Zohary & Hochstein, 1989). This study is consistent with those findings, and shows that this phenomena holds in a more ecologically valid task, in which the stimuli are words in structured layouts.

The results also support this study's fourth hypothesis – visual search for a target of known color is faster among distractors of one color than among distractors of two distinct colors. Part of this difference may be explained by the onset of color information. When just one blue word was present, participants found the target 105 ms earlier when no red words were present. Assuming an information-processing framework, information must first become available in working memory before the information can be used to guide the search process. If color were available later than layout positional information, a visual search strategy that required color information would be delayed with respect to a visual search strategy that relied entirely on positional information. This may explain some of the difference between the search times of layouts with and without red words. However, it does not account for the presence of red words slowing search more when the ratio of blue to red words is lower. As seen in Figures 8 and 9, the presence of the red words changed the search time slope.

If we consider eye movements, there are at least two possible explanations as to why the presence of red words significantly slowed the search and why this effect varied inversely to the number of blue words. Saccadic eye movements are rapid, ballistic movements that position high-resolution vision, the fovea, over the stimuli to be fixated. Fixations are pauses between saccades during which stimuli are processed and the next saccade is planned. The number of fixations is highly correlated with search time in a similar task (Hornof & Halverson, 2003). Therefore, we may consider that when search times are longer, more locations were inspected. It has also been argued that longer fixation durations are indicative of more information processing (Bellenkes, Wickens, & Kramer, 1997). Therefore, we may also hypothesize that when search times are longer, more information per fixation is processed. Figure 10 illustrates two possible explanations for the data with hypothetical eye movements: Either red words were unnecessarily processed when within the effective field of view, or they were unnecessarily used as the destination of saccades.

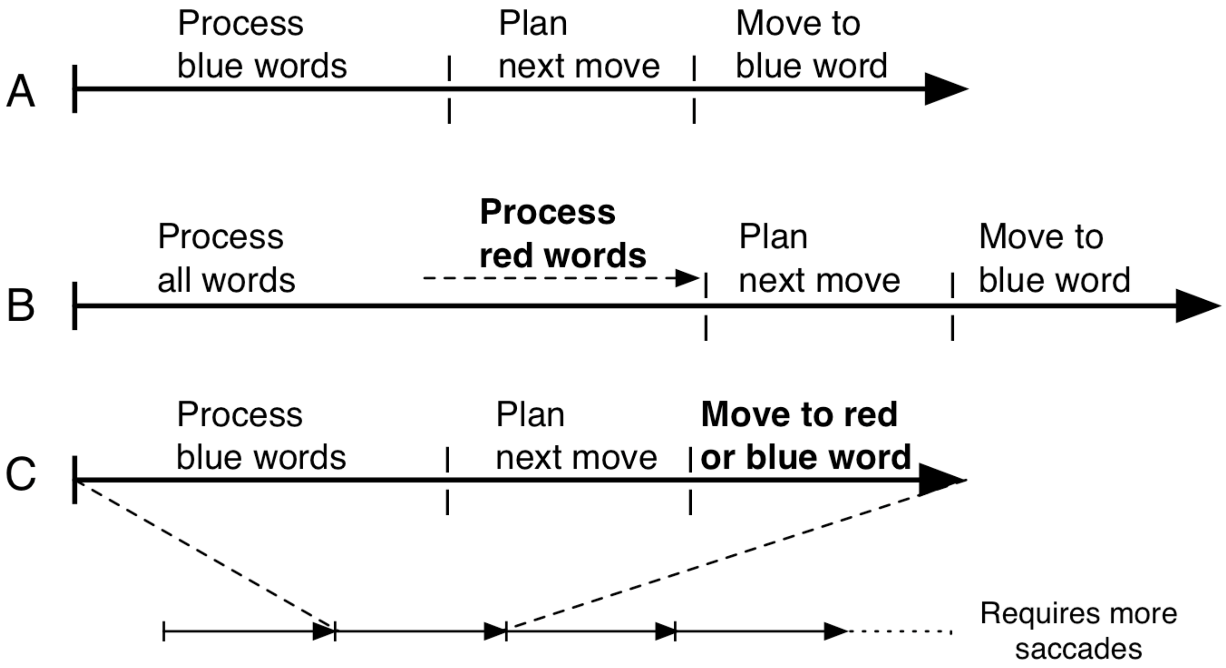

Figure 10. Three hypothetical timelines for the preparation and execution of eye movements in the link color task: Timeline A illustrates the ideal task execution in which only blue words are processed and fixated. In Timelines B and C, bold text indicates where unnecessary processing could occur in mixed-color layouts. Timeline B illustrates a suboptimal task execution in which only blue words are fixated, but some red are processed during each fixation, requiring longer fixation durations and more search time. Timeline C illustrates a suboptimal task execution in which only blue words are processed, but the eyes sometimes move to red words, resulting in more fixations and more search time.

Previous research has shown that attending to a color in a rapid serial visual presentation (RSVP) task guides the search process to spatial locations with that color, but stimuli of other colors may still be perceived (Shih & Sperling, 1996). In the current study, as the ratio of blue words to red words decreased, it was more likely that any randomly-chosen blue word would be surrounded by red words. Therefore, it is plausible that the participants processed more red words as the ratio decreased, because more words were within the effective field of view. Assuming the number of words processed in a single fixation is related to the fixation's duration, the fixation durations might have been greater when the red words were present. Further, the mean number of words processed per trial (both red and blue) would have increased as the ratio decreased, resulting in a greater search time per blue word.

Another possible explanation as to why the presence of red words affects search time is that as the ratio of blue to red words decreased the participants' likelihood of choosing a red word as the next saccade destination increased. The Guided Search Model (Wolfe, Cave, & Franzel, 1989) assumes that, due to noise, some items in the visual search display that do not share features with the known target will sometimes be selected for processing. With a greater number of red words present in the lower-ratio layouts, a greater number of red words may be "mistakenly" fixated or otherwise processed. If this were the case, then a greater ratio of fixations per blue word would result.

It is not clear from the search time data which alternative best describes the behavior. In future work, the eye movement data collected in the experiment will be used to answer this question.

Implications for design. The results of this experiment are directly relevant to design guidelines for link colors of web pages (National Cancer Institute, 2002). For tasks in which web users need only search for relevant links that have not been visited, this study shows that the visual search can be made more efficient if visited links are discernable based on color.

However, the finding that the presence of red words slows search time suggests that excluding links that are not immediately relevant to a user's goal may allow for a more efficient search. Therefore, do not assume that users will be able to selectively ignore page elements based on basic visual features, like color, that are irrelevant to the their goal, and search the page just as efficiently as if the visited links were altogether removed.

Conclusion

This research investigates the effect of two visual design elements – local density and link color – on visual search of structured, two-dimensional menus. It extends previous, basic research by investigating density and text color with more ecologically valid stimuli.

Experiment 1 shows that sparse groups of words are searched faster and, when presented with dense groups, are searched first. This lends support to the practice of displaying important information in less dense groups, with a larger font.

Experiment 2 offers empirical support for the design recommendation to differentiate visited and unvisited links by color. In addition, it indicates that omitting elements (e.g. links) not immediately relevant to the user's goals allows for more efficient search (positional constancy issues aside).

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