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Designing Interfaces for Faster Information Processing: Examination of the Effectiveness of Using Multiple Information Cues

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ABSTRACT
One of the problems studied in human-computer interaction (HCI) research is the design of interfaces that improve user information selection and processing performance. Based on prior research findings this study proposes that information selection can be improved by using multiple, supplementary cues to encode information in interface design. The research is motivated by cue-summation theory. Color and information location are proposed as relevant, supplementary cues that can improve processing performance by enhancing the reliance on a fast and automatic associative processing. Most prior studies examining the benefits of color have not controlled for information location. Our study describes a laboratory experiment in which both color and information location are employed as supplementary cues in a customer account management application. The results suggest that color and location cues significantly improve information selection and processing speed, along with user satisfaction, with the best results obtained when both cues are used.

Keywords
Cue Summation Theory, Associative processing, Information selection, Information processing, Color, Location.

INTRODUCTION
The computer interface has been defined as “the point of contact between the application and the end user” (Sheppard and Rouff, 1994, p. 1402), and as a result, the design of better interfaces is an important consideration for researchers and practitioners alike. One of the problems studied in human-computer interaction (HCI) research is the design of interfaces that improve information selection and processing performance, a relevant topic, since the use of information systems requires fast and accurate information selection. For instance, Bell System employees extract information from over 344 million displays each year using only one software package (Galitz, 1980, as cited in Wu and Yuan, 2003), while employees of a particular insurance company viewed over 4.8 million screens per year (Tullis, 1983). With organizational employees processing millions of screens a year, faster information processing per screen could quickly lead to large savings in time and cost. As such, finding ways to make users’ interaction with computers simpler and quicker is important.

In an effort to help users retrieve and process information more efficiently, the current study proposes the need to design interfaces using multiple cues to encode information, allowing users to take advantage of associative processing. Associative or peripheral processing provides information quickly and automatically, decreasing the time and effort needed to complete a task (Bargh, 1994). Our model draws on cue-summation theory, which posits that information processing and learning is more effective as the number of available cues increases (Severin, 1967). Overall this study attempts to answer the following research question:

R1: How can multiple information cues be used in computer interface design to improve information processing performance?

In the next section, the theoretical foundations will be discussed followed by a section detailing the research model and hypotheses. Later we will discuss the study design, followed by the description of the analysis and results. Lastly, the specific contributions, limitations and possible future directions of this research are explored.
THEORETICAL FOUNDATIONS AND SIGNIFICANT PRIOR RESEARCH

There are several theories and multimedia-related research streams that may inform efforts to increase information processing performance through interface design. Research in multimedia learning suggests that providing multiple cues can enhance memory and learning when the cues are relevant and evoke similar responses. The theory of cue-summation proposes that multiple relevant information cues presented in a learning environment may increase learning because these cues provide more opportunity for the learner to discern the new information being presented (Severin, 1967). This theory suggests that multiple cues presented both across and within media/channels can improve information processing and learning performance.

For the purposes of our study, we additionally propose that it is not simply the use of multiple cues that will help information selection performance, but that the design needs to provide cues in such a way that associative processing is supported. Associative processing allows for information to be processed using a fast information-processing mode based on low-effort heuristics (Chaiken and Trope, 1999). In our study, we argue for the need to enhance interface design to allow for users to rely on associative processing when retrieving information so that it becomes more efficient. In the following sections, we will review two information cues we believe can be used in interface design to support associative processing.

Color as Information Cue

Although there are numerous potential information cues that could be used, color has been the topic of many HCI-related research studies and is the primary focus of this study. Color emerged as one of the key cues for this study as: 1) color has been previously found to be the most effective coding technique for aiding visual search (Christ, 1975); 2) the processing of color precedes the processing of other attributes (i.e., Karayanidis and Michie, 1997); 3) “properly used color can be a powerful tool in improving the usefulness of an information display system” (Murch, 1984, p. 49); and 4) the use of polychromatic displays has been found to produce less eye strain and fatigue than monochrome displays (Jeffrey and Beck, 1972).

Past research has established that color is likely to influence information processing in a broad range of contexts. For example, Benbasat and Dexter (1986) studied the use of color in graphs and tables and found it to lead to improvements in decision making, especially when high time constraints were present. In their study, colors were used as labels to differentiate between sources of information such as lines in a graph. Other studies have used color to convey information about relationships between objects (e.g., maps in Yeh and Wickens, 2001), in which case the overall figure needed to be processed in order to assess the information that the color represented. Our study differs from such approaches, in that we propose to use color as a supplementary and completely redundant attribute that doesn’t require effortful processing, but rather provides alternative, faster access to the desired information by supporting automatic processing.

Location as Information Cue

The second information cue of interest in our study is the location of the target information. Information location can be used as a supplementary cue as static location allows users to form habits which can aid in navigation to target information. As such, if specific information is positioned in the same location within the interface, this information may be processed faster due to its consistent location. For example, prior literature suggests that stimuli positioned in the upper left corner of the screen are the quickest to be identified (e.g., Campbell and Maglio, 1999) The increased use of personalization techniques, however, can result in applications that dynamically change where information displays based on specific requirements. In addition, new information/data points, the changing needs of business, software updates, and general growth can result in minor and major changes in information content and location within the interface.

One unfortunate example of the effects of changing information location on information selection was documented for a computer-aided emergency dispatch launch failure which resulted in the deaths of about twenty people (Fitzgerald and Russo, 2005). However, research on this topic is very limited. Ware suggests that: “The perception of dynamic patterns is less well understood than the perception of static patterns” (Ware, 2000, p. 230) creating a chance to study a phenomenon in need of more research. Furthermore, only by creating an interaction between color and location is it possible to study the effects of color without the contaminating effects of location. Prior literature has suggested that static location (or position) is a superior selection criterion to color (Christ, 1975), but most studies have not controlled for the effect of location when examining the effects of color. Recently the use of both color and location cues (together) has been studied in the context of mobile computing, where these cues were used for innovative coding of sensitive information that could be interpreted only by the user, thereby protecting the user’s privacy (e.g., Campbell and Tarasewich, 2004, Tarasewich and Campbell, 2005). This research provides support that users can learn to associate specific meaning with both color and location cues.
RESEARCH MODEL AND HYPOTHESES DEVELOPMENT

In the previous sections, it has been suggested that the use of multiple relevant cues in application interface design will lead to faster information processing performance due to users’ ability to use associative processing. Further, research findings suggest that when available, associative processing should be preferred, since it has been documented that people try to maximize their outcomes with the least amount of effort. Allport (1954) proposed that people choose a cognitive economy strategy to be able to overcome the complexity of the stimuli in the environment. To accomplish this cognitive economy, people often develop simplifying strategies such as heuristics and schemas (Moskowitz, Skurnik and Galinsky, 1999). It is our belief that the use of supplementary information cues such as color and location in interface design can provide such heuristics for the users and allow for a faster and more automatic information selection and processing. Given our interest in studying the interplay between color and location as supplementary information cues, Figure 1 provides our research model. Specific hypotheses are presented in the next section.

![Figure 1. Research Model](image)

In order to design better systems and applications, it is important to objectively evaluate the performance benefits a new design creates for users. Performance can be measured in a variety of ways, such as speed, accuracy, or recall, as well as some combination of factors. Performance speed is a commonly used measure in research examining visual representation and its influence on performance (e.g., Benbasat et al., 1986; Dennis and Carte, 1998; Vessey, 1991). Given our focus on quicker, automatic processing, speed seemed to be an appropriate and meaningful outcome to measure. The literature suggests that both color and static information location can function as supporting cues, enabling the user to find information more quickly. The proposed hypotheses detailing the expected main effect for the use of color and location as supplementary information cues on information processing performance speed are provided below.

**H1:** The use of color as a supplementary information cue will result in faster information processing performance.

**H2:** The use of static information location as a supplementary information cue will result in faster information processing performance.

Additionally, based on the reviewed literature on cue-summation theory (Severin, 1967), we believe that information processing speed will increase with the availability of a greater number of association cues. Thus there should be an interaction between the use of color and static information location such that performance speed will be greater when both cues are used as compared to when only one cue is used. We believe that the interaction between color and location will be ordinal in nature, meaning that the regression lines will not cross. Unlike with crossover interactions, when ordinal interactions are present, the main effects of the treatments can be also interpreted (Jaccard, 1998; Rosnow and Rosenthal, 1991).

**H3:** There will be a significant ordinal interaction between color and location with faster information processing performance resulting from the simultaneous presence of both supplementary information cues.

While the objective measures of performance such as speed are very important, users’ positive attitudes and beliefs should also be considered when designing new systems. User satisfaction with information systems has been previously recognized as an important aspect to consider when developing new information systems and has also been used as a surrogate measure for IS success (DeLone and McLean, 1992). Previous studies examining the use of different information representations on task performance have also measured user satisfaction to evaluate systems’ effectiveness. For example, one study suggests that users are more satisfied with interfaces using color and other spatial cues to represent information than purely-text based representation for an information search task (Hu, Ma and Chau, 1999). Furthermore, the study results showed greater...
satisfaction levels for representations that used multiple cues (color, distance and size) to represent rank-ordering of results (Hu et al., 1999). In a different study, a group of 98 nurses evaluated a text-based and a graphical user interface-based nursing order system, and their satisfaction as well as performance was shown to be greater when using a graphical user interface (Staggers and Kobus, 2000). Thus we propose the following hypotheses about the influence of using supplementary information cues on users’ application satisfaction:

- **H4:** The use of color as a supplementary information cue will result in greater application satisfaction.
- **H5:** The use of static information location as a supplementary information cue will result in greater application satisfaction.
- **H6:** There will be a significant ordinal interaction between color and location with significantly higher satisfaction resulting from the simultaneous presence of both cues.

**RESEARCH METHOD**

In order to assess the influence of designing interfaces using multiple cues on users’ performance, a “customer account management” application and task were designed. These types of systems are used to handle the management of customer inquiries including queries regarding order filling, payments, scheduling, etc. (Te’eni, Carey, and Zhang, 2007). Given the high cost of human operators, automation and increased efficiency are primary goals for these applications.

**Study Design and Subjects**

To test the hypotheses, a 2x2 experimental design was selected, with two between-subject factors: the use of color as a cue with two levels [color-coded/colorless] and the use of location as a cue [static/dynamic]. Ten of the basic eleven colors (e.g., Jameson, 2005) were selected (white, red, yellow, green, blue, brown, purple, pink, orange, gray), excluding black color so that the color of the text could be the same for all of the account tabs. In order to represent location as a relevant cue, the versions of the application were built so that the location of the target information either stayed constant from question to question or this location randomly changed between the questions of the trial. Since experimental controls were needed in our research, we opted to use a laboratory setting. The subjects were recruited from an undergraduate; introductory IS course at a state university. Due to the importance of color in this experiment, only subjects with no impairments to their color vision were used in the analysis.

**Experimental Procedures**

The subjects were randomly assigned to four treatment conditions crossing the two factors (color and location) and followed the same procedures. All subjects received credit for their participation counting towards their final grade in the course. Subjects were further incented to participate in the study by having a chance to win a gift certificate worth $40 awarded to the subject that completed the task in the most accurate1 and timely manner. The data collection was conducted in three parts consisting of: 1) the pre-experimental questionnaire, 2) completion of the experimental task, and 3) the post-experimental questionnaire. First, the pre-experimental questionnaire collected the subjects’ demographic information and control variables2. Second, the experimenter explained the application and the task to the subjects followed by a short training period in which the subjects were allowed to interact with the application. After the subjects completed the entire experimental task, they were given a post-experimental questionnaire asking the subjects about their experience with the application.

**Experimental Task**

The experimental task asked the subjects to respond to 16 customer account management questions using the experimental application (screen shots of the experimental application are provided in the Appendix). The application used for all four treatments contained equivalent information, and all subjects were asked to find answers to the same set of 16 questions. The series of steps completed by the subjects involved 1) reading an email request from a client asking for specific account information (e.g., the current amount due on their bill), 2) finding the correct customer account/tab, and 3) finding the requested information and submitting that information back to the client. Color was manipulated in the application by using

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1 Accuracy was encouraged so that subjects would take the task seriously. The information we collected suggests that subjects made a minimal number of erroneous tab selections (about 0.6% of all selections).

2 Control variables considered in the study were: need for cognition, playfulness, visual processing and gender as these variables have been shown to influence similar tasks in past research. All information was collected using previously established measures.
colored tabs (or all grey tabs) to represent the different customer accounts in the customer account management system. Location was manipulated by changing (or not changing) the location of these customer tabs after each question. Color and static location were operationalized as supplementary cues as the name of the customer account was provided on each tab in all treatments.

In order to assess objective performance, the experimental application recorded response times (in milliseconds) for each subject to select the correct information tab (containing the specified company information) measured from the screen onset. Thus, the performance speed was measured as the time taken to find the correct company tab after reading the preceding screen describing the company’s information request.

**DATA ANALYSIS AND RESULTS**

There were 330 subjects that took part in at least one part of the experimental procedure; with 316 included in the final data analysis for an effective rate of 95% (12 subjects were color blind and 2 did not complete all parts of the experiment).

Before analyzing the hypothesized relationships, the latent structure of satisfaction with the application measured by multiple items was examined. Confirmatory factor analysis with maximum likelihood estimation was conducted on the final usable sample of 316 subjects. All items loaded above the generally recommended cut-off value of 0.7 (Nunnally, 1978) and the factor displayed good internal consistency with alpha value of 0.939, exceeding the minimum requirements (Nunnally, 1978).

The testing of hypotheses was carried out in SPSS 15.0. Objective performance speed was evaluated by averaging response time for each subject across the 16 experimental questions. Before the hypotheses were tested, we confirmed that the subjects perceived the manipulations correctly. The subjects provided a yes/no response to the following two questions: “Were the different tabs for the companies colored? (e.g., Boston Fire department = Red)”, and “Did the location of a tab for a specific company stay in the same position for all of the questions? (e.g., if the Boston Fire Department tab was always in the left most corner; you would answer yes)”. The manipulation checks were significant at p<0.000.

Hypotheses 1 and 2 tested the direct effects of the use of color and location on information processing speed. Hypothesis 1 proposed that the use of color as a supplementary cue will lead to faster information processing performance and was supported (see Table 2a) as there was a significant main effect of color on information processing performance speed (F=156.744, p<0.000). Hypothesis 2 proposed a main effect of the use of location as an additional information cue on performance speed and was also supported (F=23.425, p<0.000). Hypothesis 3 proposed a significant interaction effect between color and location. Table 2.a suggests this interaction was significant (F=5.476, p<0.020). Hypothesis 4 proposed that the use of color as a supplementary cue will lead to a greater satisfaction with the application. This hypothesis was also supported (F=24.776, p<0.000) (see Table 2.b). Hypotheses 5 proposed a significant main effect of location on application satisfaction and this hypothesis too was supported (F=5.116, p<0.024). Lastly, hypothesis 6 proposed a significant ordinal interaction between the two independent variables and this hypothesis was not supported (F=0.420, p<0.518).

<table>
<thead>
<tr>
<th>Dependent Variable: Performance Speed</th>
<th>F-value</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>25.929</td>
<td>0.000</td>
</tr>
<tr>
<td>Color</td>
<td>156.744</td>
<td>0.000</td>
</tr>
<tr>
<td>Location</td>
<td>23.425</td>
<td>0.000</td>
</tr>
<tr>
<td>Color*Location</td>
<td>5.476</td>
<td>0.020</td>
</tr>
</tbody>
</table>

Model R² = 0.372

*Note: The following control variables were entered into the model: Playfulness (F=3.542, p<0.061), Need for cognition (F=0.175, p<0.676), Gender (F=1.302, p<0.255), Visual processing (F=1.505, p<0.221)

<table>
<thead>
<tr>
<th>Dependent Variable: Application Satisfaction</th>
<th>F-value</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>6.840</td>
<td>0.000</td>
</tr>
<tr>
<td>Color</td>
<td>24.776</td>
<td>0.000</td>
</tr>
<tr>
<td>Location</td>
<td>5.116</td>
<td>0.024</td>
</tr>
<tr>
<td>Color*Location</td>
<td>0.420</td>
<td>0.518</td>
</tr>
</tbody>
</table>

Model R² = 0.135

*Note: The following control variables were entered into the model: Playfulness (F=9.089, p<0.003), Need for cognition (F=5.224, p<0.023), Gender (F=2.285, p<0.132), Visual processing (F=0.811, p<0.369)

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3 Post hoc comparisons were conducted to further assess the nature of the significant interaction between the independent variables using Schefee’s correction for multiple comparisons. This analysis revealed that the static color-coded and dynamic color-coded versions were not significantly different from each other, while all of the other comparisons were significantly different.
Tables 2.a and 2.b suggest that both color and location had a significant effect on information processing performance and both of these also had a significant direct effect on application satisfaction. Graphical representations of the reaction times for each of the sixteen questions asked are provided in Figures 3.a and 3.b below. The overall means for each treatment are represented in Figure 4. These figures provide visual evidence of color being very effective in aiding information selection and location being significant but not as helpful as color.

![Influence of Color on Information Processing Speed](image1)

![Influence of Location on Information Processing Speed](image2)

![Average Information Processing Speed by Treatment (ms)](image3)

![H3: Interaction Between Color and Location For Information Processing](image4)

Figure 3.a Reaction times (ms) for 16 questions by color

Figure 3.b Reaction times (ms) for 16 questions by location

Figure 4. Mean Performance Speed (ms) by Treatment Condition

Figure 5 provides a graphical representation of the main and interaction effects of color and location on information processing performance. The figure confirms that this significant interaction (F=6.274, p<0.013) is ordinal in nature (the lines do not cross) providing support for hypothesis 3. The trends represented in the figure show that: (1) it took people longer to find the correct information when color was not used as a cue, (2) it took people longer to locate the correct information when location was dynamically changing (static location was not provided as a cue), and (3) in the color-coded condition people were able to better overcome the dynamically changing location of the application. These results indicate that especially when there is dynamically changing information content/location in an application, it is important to design the application using multiple cues such as color to help the users overcome such cognitive constraints.

![H3: Interaction Between Color and Location For Information Processing Speed](image5)

Figure 5.a. Graph of the Interaction between Color and Location for Information Processing Speed
DISCUSSION

In this study, we have integrated theory and research findings spanning multiple disciplines to theoretically derive a model of information selection and processing performance aided by multiple cues. This model was later empirically tested and the results provide support for the overall idea of designing computer interfaces utilizing multiple supplementary cues. More specifically, the results suggest that using multiple cues in interface design can significantly improve information selection and processing speed and the use of both cues (color and static location) outperformed all of the other conditions. It appears however, that in the context of our simple task with a limited number of rounds, the use of color was sufficiently effective without the added benefit of static location. It needs to be pointed out that these results were obtained based on a population with good color-vision and similar patterns of results may not be generalizable to other populations, such as users with impairments to their color-vision in which case location or some other relevant cues may become more effective in aiding information processing performance.

Additionally, we were also interested in examining the influence of providing multiple cues on users’ satisfaction with the application. The results indicate that users would be more satisfied with an application that would be either color-coded or would be static in location supporting hypotheses 1 and 2. Even though the interaction was not significant (hypothesis 3), the highest mean value of satisfaction (5.96 on a 7-point scale) was indicated by subjects in the treatment condition which used both of the information cues, while the lowest value of satisfaction (5.03) was observed for the users in the condition which did not use either of the cues, which followed the hypothesized direction.

CONCLUSION, LIMITATIONS, FUTURE DIRECTIONS

Interacting with computer interfaces is an everyday reality for many individuals both at work and at home. It is important to look for ways of making this interaction simpler as the complexity of the information provided by many applications increases. This study investigated the performance benefits of using supplementary information cues (color and location) in interface design to encourage associative processing. The results of our study support our hypotheses for improved information processing with the use of multiple cues for a simple task. Before these results can be generalized to other settings, future research should assess the effectiveness of these cues to support information selection for more complex tasks using various different applications. It needs to be recognized, however, that despite all efforts, the study suffered some limitations that can be improved upon in future designs. These weaknesses include the omission of other perceptual variables and task/application characteristics as discussed below.

In this study, satisfaction with the application was considered as a subjective measure of preference to work with the application. There are many other variables that need to be considered in future studies to support these initial results. Additionally, while it is proposed that on average, the use of multiple cues in interface design will increase information processing performance, the strength of this relationship is expected to be moderated by contextual factors which can be grouped into four main categories: individual characteristics (e.g., visual processing, playfulness), task characteristics (e.g., task complexity, task importance), application characteristics (e.g., information density) and user-experience with the application.

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4 Preliminary analysis showed that two individual characteristics included as covariates in our study, computer playfulness and need for cognition, had significant moderating effects on application satisfaction. These effects warrant future research.
APPENDIX – SCREEN SHOTS OF EXPERIMENTAL APPLICATION

Figure 7.a Screen shot of colored experimental application

Figure 7.b Screen shot of colorless experimental application

Note: Since the location may change – the position of the tabs is not equivalent between the pictures. This is precisely how the other treatment conditions would differ.
REFERENCES


