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Designing Emergency Response Dispatch Systems for Better Dispatcher Performance

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Original Research

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Abstract

Emergency response systems are a relatively new and important area of research in the information systems community. While there is a growing body of literature in this research stream, human-computer interaction (HCI) issues concerning the design of emergency response system interfaces have received limited attention. Emergency responders often work in time pressured situations and depend on fast access to key information. One of the problems studied in HCI research is the design of interfaces to improve user information selection and processing performance. Based on cue-summation theory and research findings on parallel processing, associative processing, and hemispheric differences in information processing, this study proposes that information selection of target information in an emergency response dispatch application can be improved by using supplementary cues. Color-coding and sorting are proposed as relevant cues that can improve processing performance by providing prioritization heuristics. An experimental emergency response dispatch application is developed, and user performance is tested under conditions of varying complexity and time pressure. The results suggest that supplementary cues significantly improve performance, with better results often obtained when both cues are used. Additionally, the use of these cues becomes more beneficial as time pressure and task complexity increase.

Keywords: Information selection, color, location, sorting, interface design, emergency response systems, dispatch systems, information cues, task complexity, time pressure

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INTRODUCTION

Recently, multiple large-scale disasters have called into question the ability of emergency response personnel to adequately respond to emergency situations and the support provided by emergency response systems (ERS) (Harrison et al., 2006). If emergency personnel cannot retrieve, process, and communicate all necessary information in a timely manner, life-threatening errors and delays can result (Netten and van Someren, 2006). While progress has been made on the development of computer hardware, devices, and communication to support these emergency response environments, research is just beginning on the design and requirements of systems that can facilitate the efforts of individuals and organizations when responding to emergencies (Turoff and Van de Walle, 2004). An active research program on ERS design has begun as evidenced by the Information Systems for Crisis Response and Management (ISCRAM) international workshops and two special issues on critical information systems in the Journal of Information Technology Theory and Applications (Rothenberger et al., 2009; Turoff and Van de Walle, 2004). Recent research efforts include designing systems with optimal allocation of resources for multiple-incident response (e.g., Chen et al., 2010; Chen et al., 2005), speech and gesture driven systems (e.g., Krahnstoever et al., 2002; Sharma et al., 2003), and multi-user GIS interfaces (e.g., Rauschert et al., 2002). However, dispatch systems, which are a key component of these emergency environments, have received minimal attention, and a general call for improved interface design with ERS has been made (Chen et al., 2010).

Delays and life threatening incidents with dispatch systems further support the need for better design of these ERS components. It has been reported that people who find themselves in critical situations often need to wait for several minutes before their phone calls to 911 are picked up (Cherrie and Mellnik, 2008; SanDiegoNews, 2006). The National Emergency Number Association has set a standard for emergency call centers to answer 90 percent of calls within 10 seconds; however, reportedly only 12 states adhere to these standards, with some states and/or cities setting their own, much lower standards (Cherrie and Mellnik, 2008). Emergency centers try to solve this issue by hiring more dispatchers and operators; however, perfect staffing levels can almost never be reached because of budgetary constraints and other challenges (Cherrie and Mellnik, 2008; Stirgus and Boone, 2009). Furthermore, it is difficult for 911 call centers to respond to unplanned vacancies when it takes approximately 9 months to fully train a new employee (Ball, 2008).Thus, in addition to staffing issues, emergency centers must consider how personnel can be more efficient during times of peak demand and high stress.

Emergency dispatch systems provide essential support to emergency personnel, and this study examines the potential benefits that can be gained from designing dispatch systems that enable users to answer more calls, prioritize responses to critical calls, and handle the complexity and pressure inherent in an emergency context more effectively. In this paper, we design an experimental emergency dispatch system that uses supplementary cues (color and sorting) to encode information in an effort to improve our understanding of early information processing and selection performance. To design an emergency response test environment, we shadowed and consulted actual emergency dispatchers. Once the test environment was finalized, we conducted laboratory experiments with 514 participants to empirically evaluate different information presentation alternatives under varying conditions of time pressure and task complexity. We propose that the use of supplementary redundant cues to encode information will decrease the time and effort needed to complete dispatch tasks based on information processing theories (Bargh, 1994; Massaro and Cowan, 1993) and cue-summation theory, which posits that information processing and learning become more effective as the number of available cues increases (Severin, 1967).

In the following section, we describe existing research on emergency response systems, review decision-making steps and task characteristics, and summarize information processing theories applicable to our context. We then hypothesize the effects of supplementary cues (color and sorting) on emergency dispatcher performance. Next, we discuss the research design and experimental application and analyze the experimental results. The paper concludes with a discussion of our findings and future research opportunities.

LITERATURE REVIEW

In this literature review, we first describe the existing literature on general emergency response systems, and more specifically, that of dispatch systems. We then review the steps of a general decision-making process and decision task characteristics to better define the focus of our study on early information processing under varying levels of time pressure and task complexity. Lastly, we review information processing theories and cue summation theory to support the use of two supplementary cues (color and sorting) to improve emergency dispatch performance.

Research on Emergency Response Systems and Dispatch Systems

As mentioned, existing ERS research has primarily focused on the development of large-scale emergency response systems, devices, and communication that can support various aspects of emergency response, including training, response, and assessment (Turoff and Van de Walle, 2004). For example, research on improved data sharing has been advanced by work on an enterprise data warehouse for healthcare institutions (Bala et al., 2009), as well as through the use of better data standards (Chen et al., 2008). Large-scale integrated disaster management information systems have been advanced (Meissner et al., 2002), often based on geographic information technologies (e.g., Harrison et al., 2006; Kwan and Lee, 2005; Thomas et al., 2009). Various devices have been developed for use in the field, such as wireless sensor networks (Wilson et al., 2010; Yang et al., 2009), wearable augmented reality systems (Thomas et al., 2003), and mobile communication devices (Chittaro et al., 2007; Rossnagel et al., 2010). Research has also promoted training prior to a disaster using interactive simulation and visualization (Campbell et al., 2008) as well as improved assessment of the efficiency of these emergency systems (Kim et al., 2007). Lastly, research efforts have focused on communication within the community through the use of SMS-based emergency alert systems (Wu et al., 2008), and involving community members in the reporting of emergency situations (Palen et al., 2010; Shneiderman and Preece, 2007), which is an important consideration given the prevalence of social networking use.

More progress is needed, however, in the specific area of dispatch systems and improved human-computer interaction (Chen et al., 2010). Dispatch systems are a fundamental component of emergency management because these systems are the first systems used after an emergency response call is placed (e.g., a call to 911 in North America or to 999 in the UK) (Shen and Shaw, 2004) and support communication among the various agencies responding to an emergency incident (Chen et al., 2010; Ellington, 2004). Dispatch systems "are likely to be challenged by the high volume of incoming requests when an incident takes place… thus a system with sufficient capacity is necessary to ensure that queries and responses flow smoothly" (Chen et al., 2010, p. 145). Research on dispatch systems is beginning to emerge. One survey-based study investigated how dispatch system capacity influenced downstream asset allocation in emergency response (Chen et al., 2010); another addressed the usability of integrating GIS into dispatch systems (Ellington, 2004). Research on interface design supporting optimal performance for these critical systems has received little attention.

In our review of the existing literature on usability and interface design of ERS in general, we found that most of this prior research has focused on the initial development of interfaces for specific emergency response purposes such as mobile devices (Chittaro et al., 2007) and multi-modal interfaces (i.e., supporting speech and gestures) (Krahnstoever et al., 2002; Rauschert et al., 2002; Sharma et al., 2003). These important proof-of-concept studies created and tested novel interfaces that address specific emergency response needs, however, they were not conducted in a controlled environment designed to test alternative interface features. In fact, in a thorough review of the existing literature, we did not find any ERS interface design research that investigated the use of supplementary cues, or that empirically evaluated interface designs under varying conditions of time pressure and complexity; arguably, these two conditions are highly relevant in ERS contexts.

Decision-Making Stages and Task Characteristics

We now turn to a discussion of how the stages of decision-making apply to the decision-making support provided by a dispatch system, and how task characteristics can influence decision-making performance. The decision-making literature describes three general stages in decision-making: 1) the pre-decision stage, including information processing and selection, 2) the decision stage, including information evaluation and decision-making, and 3) the post-decision stage, which addresses feedback and learning (Einhorn and Hogarth, 1981). During the pre-decision stage, the decision-maker identifies the objectives of the decision (or receives these objectives from another party), and then processes and selects the necessary information. During the decision stage, the decision maker analyzes the information and reaches a point of satisfaction leading to a decision. In the post-decision stage, the decision outcome and results are observed, in some cases leading the decision maker to collect more data or reanalyze the data and reach a satisfactory solution. In this emergency dispatch study, we focus specifically on the pre-decision stage, in which emergency incidents are selected for processing based on the priority of the incident. Performance improvements in the pre-decision stage—such as reduced response time and cognitive effort—are essential as they provide more cognitive resources for the later stages of decision making.

Additionally, in designing interface features to improve decision-making performance, it is important to delineate the boundary conditions for performance benefits, as prior research has shown that the effectiveness of interface features depends on task characteristics (Adelman et al., 2004; Jedetski et al., 2002). Emergency response dispatchers are known to face serious time pressure with many of their tasks being quite complex (Ball, 2008). Both time pressure and task complexity are known to reduce decision-making performance, as further discussed below.

Time Pressure

Time pressure, defined here as the frequency with which the decision maker is faced with new information to be processed within a certain time period, has been shown to reduce the quality of decision-making (Payne et al., 1993) in studies spanning a variety of contexts (e.g., Aminilari and Pakath, 2005; Kocher and Sutter, 2006; Lin and Su, 1998; Sarter and Schroeder, 2001; Thomas and Wickens, 2006). Prior research suggests that decision makers under increased time pressure gather less information and process it faster, causing some individuals to use simplifying heuristics to reduce effort, potentially lowering decision accuracy (e.g., Lin and Su, 1998; Payne et al., 1988; Payne et al., 1996; Tversky, 1972). Maule and Edland (1997) further suggest that the effects of time pressure vary depending on how individuals adapt to the pressure, with some increasing their speed of processing and others increasing their selectivity of processing. The use of heuristics can thus be effective when adapted to the structure of the decision-making environment (e.g., Gigerenzer and Goldstein, 1996; Goodie and Crooks, 2004). All of these findings point toward an opportunity to use appropriate interface design to support preferred heuristics for easing cognitive load during time-pressured situations. In the context of emergency management, researchers note that system use is different during a crisis situation than during routine use, reflecting more rapid and reactive actions than more deliberate and calculated ones (Adrot and Pallud, 2009). Sarter and Schreder (2001) further comment on the surprisingly small number of studies addressing the effectiveness of different forms of decision support under time pressure.

Task Complexity

Task complexity can be described as the number of specific stimuli that need to be processed to select appropriate information stimulus or stimuli for further processing and decision-making (Wood, 1986). According to research examining pre-attentive processing, a person's reaction time to a given stimulus depends on the amount of material to be processed, even if it is presented outside the focus of attention (Schweizer, 1994; Schweizer, 1995). Multiple studies investigating the relationship between task complexity and various decision-making performance measures have found performance to degrade as complexity increases (e.g., Byström and Järvelin, 1995; Crossland et al., 1995; Mennecke et al., 2000; Swink and Robinson, 1997). Similar to the effects of time pressure, increased task complexity demands increase cognitive effort, and users reach for satisficing strategies in decision-making in an attempt to decrease effort (e.g., Paquette and Kida, 1988). Prior research supports the idea of using visual cues to ease processing for complex tasks, especially if the visual cues are well-aligned with processing needs (e.g., Crossland et al., 1995; Mennecke et al., 2000; Speier, 2006; Umanath and Vessey, 1994). These findings suggest that the appropriate use of visual cues may improve information processing for users dealing with complex tasks.

Information Processing Theories

The following section briefly reviews theories that address how information processing can be differentiated, and how these differences influence the speed of information selection. In particular, we explore how specific types of supplementary cues (i.e., visual cues) can improve decision-making performance in the pre-decision/early information processing stage.

Parallel vs. Serial Processing

Information processing can be differentiated based on the way in which multiple pieces of information (stimuli) presented at the same time can be processed. When information is processed using serial (sequential) processing, only one item can be processed at a time, while the use of parallel processing allows multiple items to be processed simultaneously. A person's ability to use parallel rather than serial processing is usually determined by the type of stimuli the person is attending to. During the pre-decision stage, in which multiple stimuli or cues are presented and information selection occurs, a decision maker could benefit from parallel processing as more information could be simultaneously acquired. Supplementary cues can be used in interface design to enable parallel processing that is faster and more efficient. The specific cues that can be used to create these benefits are introduced in later sections; the next section examines hemispheric differences in human processing and their implications for our research.

Hemispheric Differences in Processing

Information processing can also be evaluated based on the hemisphere that dominates the specific cognitive function used. Prior research findings indicate that the right hemisphere specializes in visual and spatial functions and processes such information efficiently in a synthetic, holistic manner (Levy, 1974), while the left hemisphere is responsible for language expression and processing, which is conducted in a sequential manner (i.e., Barton et al., 1965; Geffen et al., 1971; Mishkin and Forgays, 1952; Rizzolatti et al., 1971; Springer and Deutsch, 1981). These hemispheric differences are not absolute and functions are not solely performed by one hemisphere or the other; however, certain tasks have been found to be performed more efficiently by shifting reliance towards the right hemisphere and more holistic processing. The information processing and selection that occurs in the pre-decision stage might be improved through the use of visuo-spatial (non-verbal) cues in an interface design. Such visuo-spatial cues would likely be processed more efficiently by the right hemisphere, rather than by the more serial language processing approach used in the left hemisphere. Lastly, information processing can either take the form of associative processing or symbolic processing; this distinction will be examined in the following section.

Associative vs. Symbolic Processing

Associative processing provides information very quickly and automatically, and operates preconsciously (Bargh, 1994). This processing relies on associations and is used when information has been repeatedly linked to a certain response (Smith and DeCoster, 2000). Consistent mapping of the characteristics of an object to a response leads to the automatic detection of the target object, increasing information processing performance (Cousineau and Larochelle, 2004). In contrast, symbolic processing is sequential, following a step-by-step logic (Sloman, 1996) and is used for higher-level decision making and linguistic functions. When both processing types are available, most people will use the faster and relatively effortless associative processing. One of the drawbacks of associative processing, however, is the need to establish links between the associations and their related information. Research has shown that it may be possible to speed up association formation by giving instructions about what associations need to be made (Schneider and Chein, 2003). Consequently, associating information with specific cues can facilitate the use of associative processing. Such design improvements may be especially beneficial in the pre-decision stage, when speed of information selection is paramount.

In summary, these information processing theories explain how information selection and processing can be influenced by the careful design of user interfaces using different types of stimuli. Next, cue summation theory is examined since it provides supportive theoretical justification for why it may be beneficial to use a combination of cues (or stimuli) in the design of ERS applications. An overview of two specific information cues that can be used to speed up pre-decision information processing and selection is also provided.

Cue-Summation Theory

Research in multimedia learning proposes that providing multiple cues can enhance memory and learning when the cues provide similar content and evoke similar responses. The theory of cue-summation suggests that this use of multiple, redundant cues provides individuals with more opportunity to discern the information being presented, and thus facilitates learning (Severin, 1967). Similarly, the use of multiple cues has been examined with respect to communication effectiveness, where media that allow for multiple information cues to be exchanged are generally seen as “richer” (e.g., Daft and Lengel, 1986), and are often times seen as better able to communicate a message to the receiver. However, Miller (1957, p. 78) points out that:

> *When cues from different modalities (or different cues within the same modality) are used simultaneously, they may either facilitate or interfere with each other. When cues elicit the same response simultaneously… they should summate to yield increased effectiveness. When the cues elicit incompatible responses, they should produce conflict and interference.*

In other words, it is not merely the number of cues, but rather the information that the cues convey that creates the positive or negative effects on performance. In this study, we propose that the use of redundant, visuo-spatial cues in interface design can heighten the use of the right hemisphere as well as associative and parallel processing, resulting in more efficient information processing and selection in the pre-decision stage. A redundant cue (stimulus) provides information that is already conveyed in the interface but in a different modality or form (e.g., color–coding of a high-priority incident when incident priority is already described in a textual format). The next two sections outline two visuo-spatial cues: color and sorting, which can be used as supplementary information cues in interface design to improve performance.

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. Prior research has shown that color is likely to influence information processing in a variety of contexts. For instance, Benbasat and Dexter (1986) found that color improved decision making when used for labeling in tables and graphs, especially when high time constraints were present. Likewise, Keller and colleagues (2006) found that color-coded information visualization improved knowledge acquisition. Here, it is proposed that color-coding can be used as a visual supplementary cue that may provide alternative, faster access to the desired information by supporting associative/parallel processing.

Furthermore, research findings suggest that the processing of colors is different from and precedes the processing of words. Recent findings, using neuroimaging for cross-function comparisons, confirm the notion that different areas of the brain activate depending on different types of stimuli (e.g., Cabeza and Nyberg, 2003), with the left hemisphere attending to verbal cue processing and the right hemisphere attending to visuo-spatial cue processing. Research has also provided evidence of a sensory precedence for processing of various stimuli (Proverbio et al., 1998), with color taking precedence over relatively specific and detailed non-spatial attributes such as the size or shape of letters or other objects (i.e.,Karayanidis and Michie, 1997). The fast processing of colors can be further supported by recent findings that the overall evaluation of the visual appeal of a website (mostly the aesthetic value of the design) can be assessed within the first 50 milliseconds of the stimulus onset (Lindgaard et al., 2006), while eye fixation on one word when reading is estimated to take 250 ms (Sereno et al., 1998). The aforementioned studies suggest that color will be processed prior to any other information on an information display, making this cue very effective in aiding information processing and selection during the pre-decision stage of decision making.

Sorting as a Location Information Cue

Sorting or ordering information by specific attributes has been shown to be a valuable decision aid, reducing search time since users can look for target information in a specific location of the list based on sorting criteria (Cai and Xu, 2008; Hong et al., 2004; Schmutz et al., 2010). Experimental studies on sorting have shown that sorting in descending (based on the most relevant criteria) rather than ascending order reduces search time as the target information is displayed at the top of a display and the need for scrolling is reduced (Cai and Xu, 2008). In addition, sorting places list items with similar characteristics next to one another, in closer proximity, thus reducing search time for the next most relevant item in the list (Hong et al., 2004; Wickens and Carswell, 1995).

Sorting information based on certain criteria offers additional benefits because the location or spatial arrangement of information can serve as a supplementary cue. Prior research has shown that visual search is more efficient if the target information is displayed in the same location (Pearson and Van Schaik, 2003). When there is a consistent mapping between visual display location and information content, users can form an association between the location and the target information, supporting associative processing. Because location is a visuo-spatial cue, it facilitates faster holistic processing by the right hemisphere of the brain. The mapping of location to information content can be further optimized by positioning the target information in specific areas of the display based on the documented visual search patterns of left to right and top to bottom, a clock-wise scan of the display (e.g., Campbell and Maglio, 1999; Schmutz et al., 2010).

In other words, a sorted list with the most important items listed first (i.e., descending order), provides an association between location (top of the list/display) and the target information, and also provides an association between the more relevant items in a list by locating them close together. These supplementary information cues enable users to quickly find the most relevant target information, and the next most relevant information using spatial location, which reduces the need for textual, symbolic processing.

Limited research has examined color and location/sorting cues (together) in interface design. One study in the context of mobile computing found that sensitive information could be coded and successfully conveyed solely through color and location, 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, but used color and location as primary cues rather than supplementary cues. We now present our hypotheses on how supplementary cues in interface design can improve information processing performance.

DEVELOPMENT OF HYPOTHESES

Drawing on the literature reviewed in the previous sections, we propose a research model (Figure 1) and a set of hypotheses that can be used to evaluate the benefits of designing emergency dispatch interfaces that support more efficient information processing and selection in the pre-decision stage.

Emergency dispatch environments are characterized by a high volume of emergency incidents, with some centers handling thousands of calls per day (Fitzgerald and Russo, 2005). Dispatchers often interact with screens filled with incoming information collected from multiple 911 calls/incidents, and they must determine which calls to select and process based on the priority of the incident (i.e., immediate danger to persons and/or property). Incident codes are standardized such that a combination of letters describes the nature and priority of the incident (i.e., PROPFIRE represents property fire) (Ball, 2008). Once the dispatchers identify the incident to respond to, they select it and engage in later decision-making to send the necessary resources to assist the victims. During our shadowing of dispatchers, we observed that the ERS used to support dispatchers provide basic functionality, displaying the incoming incidents, enabling the dispatcher to allocate the appropriate resources, but support for enabling more efficient processing of incidents is often not provided or utilized.

Interfaces designed with supplementary, redundant cues of a visuo-spatial nature should facilitate faster information selection by enabling more efficient forms of information processing. Additional cues (i.e., color and sorting) can convey information that is already provided in the incident code, but the visuo-spatial nature of these cues would enable dispatchers to process information using parallel or associative processing. For example, a dispatcher would recognize an incident with the code PROPFIRE as a higher priority, critical incident using more symbolic, sequential processing. However, the priority of this incident could be redundantly conveyed with red for highest-priority and/or sorted to the top of a list to enable more associative, parallel processing. More specifically, research suggests that the global nature of color will be processed faster than the more detailed verbal information (e.g., Lindgaard et al., 2006; Proverbio et al., 1998), because color stimuli are processed relying on parallel rather than sequential processing (Massaro and Cowan, 1993). Similarly, users would be able to form habitual associations to the sorted location of relevant information, allowing them to use associative processing that is relatively effortless and faster compared to symbolic processing. Sorting incidents by priority in descending order will consistently place the highest priority incidents at the top of the list, leading to automatic detection of target information and increased information processing performance (Cousineau and Larochelle, 2004). Furthermore, cue-summation theory suggests that when multiple cues are available, information processing and learning can be improved (Severin, 1967). Color and/or sorting can serve as redundant cues to the information provided in the incident code that may improve information processing performance.

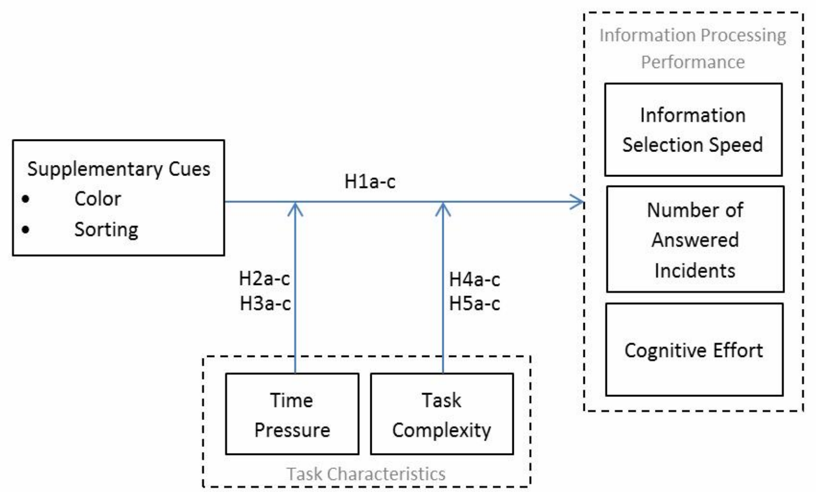

Figure 1: Research Model

Performance in the pre-decision stage can be measured in a variety of ways, such as speed, the number of tasks completed, the effort required, or accuracy, as well as some combination of these factors. Performance speed or response time is a commonly used measure in research examining visual representation and its influence on performance (e.g., Benbasat and Dexter, 1986; Dennis and Carte, 1998; Vessey, 1991; Vessey and Galletta, 1991). Given that the focus of the study is on quicker, automatic processing for emergency response dispatchers, information selection speed is an appropriate and meaningful outcome to measure for ERS. Color and sorting, as supplementary visuo-spatial cues, should enable faster information selection through parallel and associative processing. Additionally, cue summation theory suggests that providing multiple confirming cues will provide more opportunity for the dispatcher to notice and process the cue. Thus, we propose the following:

> *H1a: Designing ERS interfaces with supplementary information cues (color and sorting) will improve dispatcher information selection speed.*

In addition to improving information selection speed, these supplementary cues should also increase the number of incidents that dispatchers can process. Improvements in response efficiency should enable dispatchers to respond to more incidents during a given period of time. In addition, the associations formed with these supplementary cues make it easier for dispatchers to find the next high priority incident (through similar color or location in a sorted list). Dispatchers will be able to move more quickly to the next incident and thus will be able to process more incidents. Thus we propose the following:

> *H1b: Designing ERS interfaces with supplementary information cues (color and sorting) will increase the number of answered incidents.*

In addition to objective measures of information selection performance, users' perceptions should also be considered when designing new systems; especially when cognitive processes are involved that cannot be assessed solely through objective measures. This study also explores the effectiveness of the selected supplementary cues in decreasing perceived cognitive effort, since it is suggested that both parallel and associative processing are associated with lower cognitive costs. Cognitive effort can be defined as "the engaged portion of limited capacity central processing" (Tyler et al., 1979, p. 607), which is important to assess since people's attentional resources are limited (Kahneman, 1973). It is crucial to try to actively decrease cognitive effort, because if unmanaged, users will consequently search for strategies to simplify their task which may result in lower performance (Todd and Benbasat, 1999). This natural strategy of using heuristics when dealing with complex situations can be turned into an advantage if interfaces are designed to decrease users' cognitive effort. Thus, we propose that:

> *H1c: Designing ERS interfaces with supplementary cues (color and sorting) will result in lower perceived cognitive effort.*

As previously discussed, time pressure and task complexity are common characteristics of dispatchers' work environments, and are known to erode decision-making performance. In the following sections, we propose hypotheses that examine the mitigating effects of supplementary cues on dispatchers' performance under varied levels of time pressure and task complexity.

Time Pressure and Its Effects on Users' Performance

Performance under time pressure has been examined across various disciplines for different tasks (e.g., Benbasat and Dexter, 1986; Bronner, 1982; Dhar and Nowlis, 1999; Hwang, 1994; Hwang, 1995; Rothstein, 1986), and time pressure has generally been found to adversely affect performance. In IS research, however, few studies have examined the influence of time pressure on performance (Marsden et al., 2002). In this study we examine the effects of time pressure on users' performance in the context of dispatch systems, as dispatchers are often under severe time pressure (Ball, 2008). More specifically, this study explores the interplay between the use of supplementary information cues and different levels of time pressure in an effort to better understand the effectiveness of these cues in time-pressured situations. Time pressure effectively reduces cognitive resources, and people often try to deal with limited cognitive resources by actively seeking strategies such as simplifying heuristics (Moskowitz et al., 1999). We propose that in situations of high time pressure, supplementary cues will be more effective at improving users' performance because they allow emergency dispatchers to use these cues as heuristics to simplify the selection and processing of high priority incidents. Such heuristics may not be necessary or not as helpful in low time pressure situations when dispatchers have enough cognitive resources available to perform their tasks. Thus it is proposed that:

> *H2a: The use of supplementary cues will be more effective at improving dispatcher information selection speed under greater time pressure than under lower time pressure.*

> *H2b: The use of supplementary cues will be more effective at increasing the number of answered incidents under greater time pressure than under lower time pressure.*

> *H2c: The use of supplementary cues will be more effective at decreasing perceived cognitive effort under greater time pressure than under lower time pressure.*

Additionally, based on information processing theories and cue-summation theory, it is further proposed that the use of multiple supplementary cues concurrently (e.g., color and sorting) will lead to greater improvements in performance in high time pressure situations by giving users various ways of decreasing their cognitive strain. The availability of two supplementary cues will provide the user with more opportunity to process information in parallel or use associative processing which have both been shown to improve speed and reduce effort. The dispatcher is also less likely to overlook a high priority incident when color and sorting location cues are associated with it. Thus we propose that:

> *H3a: In high time pressure situations, the use of two supplementary cues will be more effective at improving dispatcher information selection speed than the use of only one supplementary cue.*

> *H3b: In high time pressure situations, the use of two supplementary cues will be more effective at increasing the number of answered incidents than the use of only one supplementary cue.*

> *H3c: In high time pressure situations, the use of two supplementary cues will be more effective at decreasing perceived cognitive effort than the use of only one supplementary cue.*

In the next section, we examine the interplay between task complexity and the use of supplementary cues in high time pressure situations, providing specific hypotheses.

Task Complexity and Its Effects on Users' Performance

Generally, task complexity has been found to reduce information processing performance, and has been examined across a range of disciplines, including IS (e.g., Byström and Järvelin, 1995; Paquette and Kida, 1988; Wood, 1986). Task complexity is a natural aspect of an ERS environment, where personnel often have to attend to multiple emergency incidents simultaneously. Prior research has shown that greater task complexity increases cognitive processing requirements (Klemz and Gruca, 2003; Speier, 2003; Zigurs and Buckland, 1998). Additionally, it has been suggested that information selection (such as in the pre-decision stage) becomes driven by the selection of specific attributes (e.g., higher-priority incidents) when the task gets more complex (Payne et al., 1993). With increased complexity, users have reduced cognitive capacity and may need to focus solely on those tasks/incidents that meet a certain attribute cut-off value (e.g., highest priority). All alternatives that don't meet this cut-off are eliminated from further processing (Payne et al., 1993). In an emergency dispatch context, the use of color and/or sorting as cues will let users form associations and then apply heuristics to ignore or postpone dealing with incidents that are not of a high priority. The availability of color and/or sorting supplementary cues will be more effective for higher complexity tasks, as these cues are needed to reduce complexity, allowing dispatchers to focus on a subset of incidents that are of high priority. Alternatively, in a lower-complexity environment, supplementary cues will provide fewer benefits for achieving desired decision performance. Thus, we propose:

> *H4a: The use of supplementary cues will be more effective at improving dispatcher information selection speed for more complex tasks than for less complex tasks.*
>
> *H4b: The use of supplementary cues will be more effective at increasing the number of answered incidents for more complex tasks than for less complex tasks.*
>
> *H4c: The use of supplementary cues will be more effective at decreasing perceived cognitive effort for more complex tasks than for less complex tasks.*

Lastly, task complexity and time pressure have also been shown to interact, where time pressure is expected to have different effects on simple vs. complex tasks such that cognitive resources are further reduced when both complexity and time pressure are high (Hahn et al., 1992; Hwang, 1995). In this context, two supplementary cues, encouraging associative and parallel processing and reiterating the priority of each incident, may be needed to overcome the increased cognitive demands. Thus, we propose:

> *H5a: In high time pressure situations, the use of two supplementary cues will be more effective at improving dispatcher information selection speed for more complex tasks than for less complex tasks.*
>
> *H5b: In high time pressure situations, the use of two supplementary cues will be more effective at increasing the number of answered incidents for more complex tasks than for less complex tasks.*
>
> *H5c: In high time pressure situations, the use of two supplementary cues will be more effective at decreasing perceived cognitive effort for more complex tasks than for less complex tasks.*

RESEARCH DESIGN

To test the hypothesized model, two experimental studies were conducted. The first study followed a 2x2x2 full-factorial experimental design, with three between-subject factors: the use of color as a cue with two levels (color-coded/colorless), the use of sorting as a supplementary information cue with two levels (sorted by priority/and unsorted[1]) and time pressure with two levels (low/high). The second study explored the high time pressure scenario more thoroughly; where high time pressure was maintained in all conditions. For this study a 2x2x2 experimental design was used with three between-subject factors: color-coding (color-coded/colorless), sorting (sorted/unsorted) and task complexity (low/high).

Experimental Emergency Dispatch Application

An experimental emergency dispatch application was developed for use in both studies. The application was developed after extensive shadowing of local dispatchers and based on previous work in the area (Joslyn and Hunt, 1998). The experimental application used a two-step approach that is utilized by many emergency dispatch systems where emergency operators first answer incoming calls and input the relevant facts from these calls into the system.

Next, dispatchers monitor their system for new incidents (entered by others), and after reviewing the specifics of a particular incident, dispatch the appropriate emergency personnel. To view the full description of any given incident, the dispatcher first has to select an incident from a list of all reported incidents.

Color-coding was implemented in the application through the use of adapted triage coding[2]; with red color indicating the highest priority, critical incidents followed by orange, yellow and green for the lowest-level of priority. Two other colors were included: white was used to differentiate special cases that were so called follow-ups from ambulances and blue was given to follow-ups from police officers. These special types of reports were included based on the practices of local dispatchers and prior research (Joslyn and Hunt, 1998). Colorless versions of the application used grey for all of these incidents. Figure 2 provides a screenshot of a color-coded treatment, while Figure 3 provides a screenshot of a colorless treatment.

Sorting was operationalized in the experimental application as a supplementary cue such that the reported incidents were ordered and listed by their priority level, with the highest priority incidents appearing at the top of the list. Incident reports were displayed in chronological order within each priority location. Figure 2 provides a screenshot of a sorted treatment, while Figure 3 depicts an unsorted treatment. The unsorted version of the application lists the incidents in chronological order, which was also the ordering used by the local dispatchers.

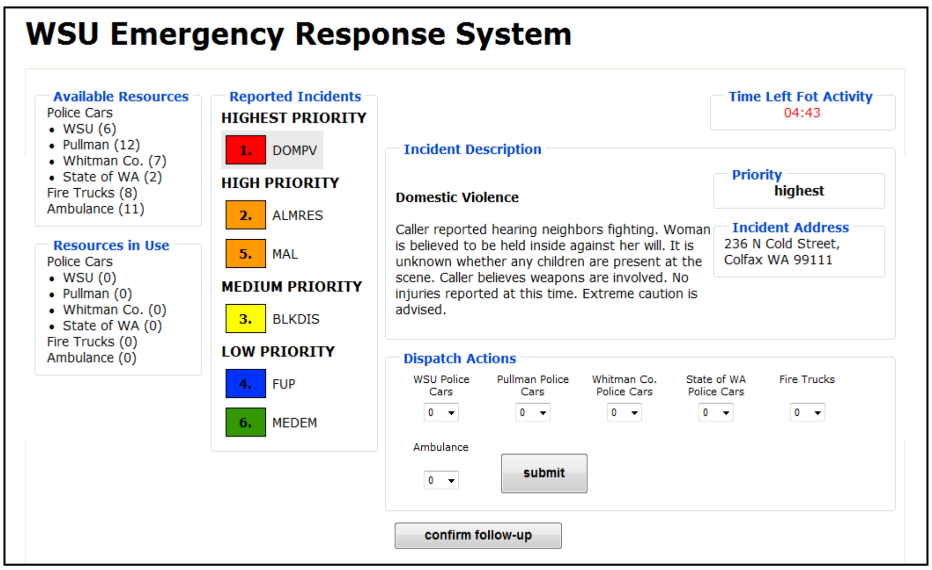

Figure 2: Application Screenshot: Color-Coded and Sorted

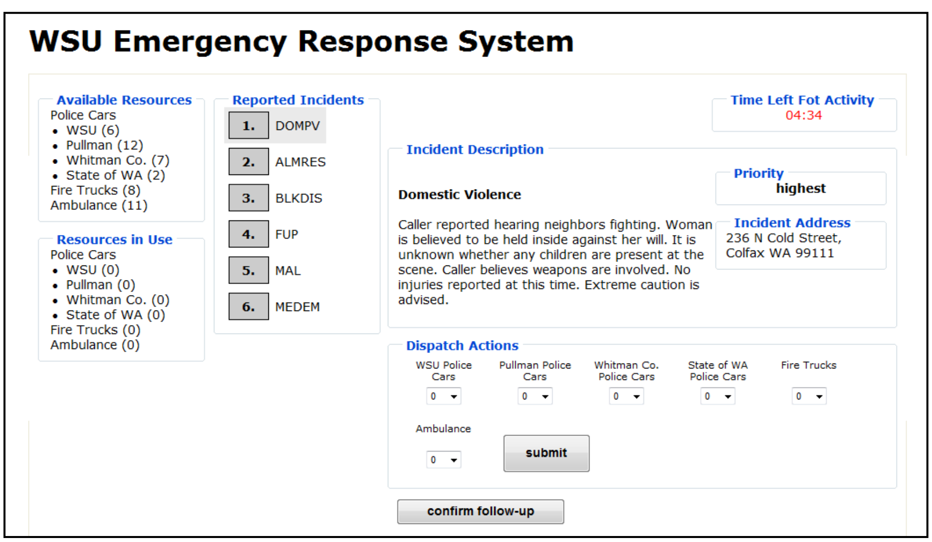

Figure 3: Application Screenshot: Colorless and Unsorted

Both color-coding and information sorting by location were operationalized as supplementary and redundant information cues, as a text code was provided for each incident that described the nature and the priority of the incident (e.g., MEDEM is a medical emergency, TRFCOL is a traffic collision). These types of codes are commonly used in most dispatch/emergency response contexts. Emergency responders heavily rely on these codes because key facts regarding the incident are conveyed efficiently through a few letters. The participants were given a list of codes with descriptions and corresponding priority levels (highest, high, medium, or low) and thus were able to find the highest priority incidents without the help of the supplementary cues (see Appendix A for a complete listing of codes, and corresponding priority levels, used in these studies)[3].

The time pressure and task complexity manipulation levels were established through a series of pilot studies. Specifically, time pressure was manipulated by changing the frequency in which the incidents were reported in the application, with the low time pressure condition generating incidents every 30 seconds over a 5 minute period, and the high time pressure condition generating incidents every 15 seconds over a 5 minute period. Additionally, the application was seeded with a starting number of incidents that were immediately available for the dispatchers to answer. There were 3 starting incidents in the low time pressure condition with new incidents generated every 30 seconds for a total of 13 incidents. In the high pressure condition, there were 4 starting incidents with new incidents generated every 15 seconds for a total of 24 incidents. Task complexity was operationalized at low and high levels by varying the percentage of incidents that were higher priority. Higher priority incidents generally require more dispatcher actions, such as dispatching a greater number and variety of emergency cars and trucks. In high complexity mode, 1/3 of the incidents were coded as critical (the highest level of priority), while in low complexity mode, 1/6 of incidents were coded as critical.

In summary, in Study 1, color (color-coded/colorless), location sorting (sorted/unsorted), and time pressure (low/high) were operationalized by the experimental application. In Study 2, time pressure was maintained at a high level, complexity assumed two different levels (low/high), and both of the supplementary cues varied.

Participants

The participants were recruited from an undergraduate, introductory MIS course at a university in the United States, and were given extra credit toward their grade in the class for their participation. As further incentive, participants had a chance to win a gift certificate worth $10, which would be awarded to the participants who completed the task in the most accurate and timely manner in each laboratory session. Due to the importance of color in this experiment, only participants with unimpaired color vision were included in the analysis.

Experimental Procedures

Data for this study was collected in a controlled laboratory setting. 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, participants responded to pre-experimental questionnaire items that provided information about some demographics and individual differences (discussed later). Second, the experimenter explained the application and the task to the participants and gave them the opportunity to interact with the application for a 3-minute training period. This training period was followed by a 5-minute practice session in which the participants interacted with the application in the same manner in which they subsequently completed the experimental task. Pilot testing ensured that participants received adequate training, as they on average answered 69% of all incidents within the 5 minute training period, with 30% of the participants completing above 80% of the given incidents. After the participants completed the entire experimental task, they were given a post-experimental questionnaire addressing their experience with the application.

Experimental Task

The experimental task asked the participants to put themselves into the scenario of an emergency response dispatcher. The participants were told that emergency response operators had already taken the incoming 911 calls and entered the necessary information into the computer assisted dispatching system. The participants’ task was to read the incoming incidents and dispatch the necessary resources. They were asked to dispatch these incidents as quickly and accurately as possible; and to process the incidents by priority with the highest priority incidents being processed first. The participants received a written set of rules by which to decide what resources to use for certain types of incidents, and were essentially given all information necessary to complete each task correctly. A copy of these instructions and rules is provided in Appendix A. The series of steps completed by the participants involved 1) looking at the list of the reported incidents and selecting the one they wanted to dispatch (presumably the one with the highest assigned priority), 2) reading the detailed information about the incident provided by the system, 3) making a decision about the appropriate response based on the rules provided to them, 4) selecting the resources to dispatch for that specific incident, and 5) submitting the answer. At this point, the participant moved on to the next incident.

Measures

One individual difference scale, computer playfulness (Webster and Martocchio, 1992), was included in the pre-questionnaire as a control variable to assess whether the participants' general attitude toward computer use might impact their performance with the application. All scales are provided in Appendix B. Information processing performance was assessed using multiple measures: 1) perceived cognitive effort, 2) number of answered incidents, and 3) information selection speed. Cognitive effort was measured in the post-questionnaire using items developed for the purposes of this study and previously validated in a pilot data collection. Total number of answered incidents was computed as a percentage of incidents answered by the participant out of the total possible for the task. As previously described, in the low time pressure conditions, participants were given a total of 13 incidents and in the high time pressure condition they faced 24. Information selection performance speed was computed as an average of response times for the highest priority incidents, as participants were told to process the higher priority incidents first[4]. The number of such incidents differed by treatment. In Study 1, 3 of the 13 incidents (23%) in the low time pressure condition were highest priority, and 5 of the 24 incidents (21%) were highest priority in the high time pressure condition. In Study 2, 4 of 24 incidents (1/6th or 16.7%) were highest priority in the low complexity, high time pressure condition, while 8 of 24 incidents (1/3rd or 33.3%) were highest priority in the high time pressure, high complexity condition. Additionally, for each incident that participants did not respond to, they were given a penalty of the total time this incident appeared on their screen (time from when it appeared until the end of the experiment), which was also included in the calculated mean if applicable.

ANALYSIS AND RESULTS

There were 335 participants who participated in Study 1, and a different sample of 326 participants who participated in Study 2, for a combined sample size of 661. Seventeen cases were deleted because participants reported abnormal color-vision, and fifteen cases were deleted because those participants did not complete all parts of the study (e.g., the post-survey), resulting in 629 cases. Additionally, 43 cases were deleted because those participants attempted a minimal number of tasks during the five minute period, indicating that they did not participate in the task thoughtfully. Participants completing fewer than 30% of the tasks were not included in further analysis. Lastly, we collected data for three treatments in three extra sections (16 treatments, with 19 lab sections) to provide all students with the specified extra credit opportunity. These extra sections were not included in our analysis, as it would have doubled the number of participants in 3 of the 16 treatments. After excluding 72 participants from these three additional sections, the final sample size was 514 participants with cell sizes ranging between 23 and 37, as the number of participants varied by lab sections.

Manipulation Checks and Descriptive Statistics

Manipulations were first tested to ensure that participants perceived the treatments properly. To test the participants' perceptions of time pressure, they were asked to respond to the following question: "I feel the new incidents were reported to the system:" with two semantic sets of anchors - very infrequently (1) to very frequently (7), and very slowly (1) to very quickly (7). The mean differences were both significant ($F(1, 512)=183.98$, $p<.001$; $F(1, 512)=187.89$, $p<.001$), lending support to the appropriate perception of the time pressure manipulation by the participants. To assess complexity, the participants were asked to respond to the following question: "Overall this task was:" with two semantic sets of anchors - very complex (1) to very simple (7), and very difficult (1) to very easy (7). The mean differences were both significant ($F(1, 512)=22.93$, $p<.001$; $F(1, 512)=34.57$, $p<.001$). To assess the participants' perception of the availability of color-coding and sorting as supplementary cues, they responded (yes/no) to the following two questions: "Were the reported incidents organized by color?" and "Were the reported incidents sorted and listed by the application by priority?" Both manipulation checks were supported ($F(1, 512)=1052.12$, $p<.001$ and $F(1, 512)=725.42$, $p<.001$). These results suggest that the participants accurately perceived the manipulated conditions. In addition, we evaluated selection speeds by priority to ensure that participants selected the highest priority incidents first for processing as instructed. The mean selection times (highest=15.5, high=28.1, medium=69.6, and low=100.8) provide evidence that participants did prioritize appropriately.

Descriptive statistics by measure for each treatment in both studies are provided in Table 1. The average age of the participants was 20.1, ranging from 18-30, and 39% of the participants were female. The reliability of the two measured constructs, computer playfulness and perceived cognitive effort were assessed (Cronbach's alphas were .77 and .94, respectively) and found to exceed the recommended threshold of .7. Computer playfulness was included in the initial analysis as a control variable and was found to have no effect on the measured dependent variables.

Table 1: Table of Means by Treatments for both Studies 1 and 2

Treatment Condition		***Variables***	***Lower Complexity***			***Higher Complexity***
		(Number of Highest Priority Incidents)	3 of 13 (23%)	4 of 24 (17%)	5 of 24 (21%)	8 of 24 (33%)
Sorted	**With Color**		**Low Time Pressure (Study 1)**	**High Time Pressure (Study 2)**	**High Time Pressure (Study 1)**	**High Time Pressure (Study 2)**
			Mean (St.Dev.)	Mean (St.Dev.)	Mean (St.Dev.)	Mean (St.Dev.)
		Sample Size	33	37	27	34
		Overall Performance [%]	91.99 (3.46)	87.05 (12.30)	79.49 (15.02)	77.57 (13.37)
		Critical Incident Response Time [s]	5.13 (5.69)	5.06 (2.63)	6.18 (2.20)	12.02 (20.56)
		Perceived Cognitive Effort	2.76 (0.99)	2.82 (1.11)	2.43 (0.73)	2.82 (0.93)
	No Color		**Low Time Pressure**	**High Time Pressure**	**High Time Pressure**	**High Time Pressure**
		Sample Size	30	37	29	36
		Overall Performance [%]	90.24 (5.46)	83.33 (13.06)	78.30 (18.04)	74.07 (17.79)
		Critical Incident Response Time [s]	9.57 (14.81)	12.82 (21.36)	10.31 (11.94)	16.74 (17.01)
		Perceived Cognitive Effort	2.82 (1.28)	2.99 (1.04)	2.93 (1.22)	3.06 (1.03)
Unsorted	**With Color**		**Low Time Pressure**	**High Time Pressure**	**High Time Pressure**	**High Time Pressure**
		Sample Size	23	31	29	32
		Overall Performance [%]	91.61 (4.12)	82.39 (14.97)	77.16 (17.80)	77.99 (16.77)
		Critical Incident Response Time [s]	7.52 (10.28)	17.69 (33.90)	10.64 (10.81)	14.91 (21.77)
		Perceived Cognitive Effort	2.78 (1.04)	3.40 (1.11)	3.24 (1.49)	3.16 (1.08)
	No Color		**Low Time Pressure**	**High Time Pressure**	**High Time Pressure**	**High Time Pressure**
		Sample Size	34	33	32	37
		Overall Performance [%]	91.39 (4.23)	82.45 (15.51)	73.05 (17.65)	68.02 (16.64)
		Critical Incident Response Time [s]	10.33 (9.95)	30.26 (27.24)	32.93 (26.22)	39.44 (26.68)
		Perceived Cognitive Effort	3.32 (1.25)	4.12 (1.02)	4.25 (1.24)	4.16 (1.19)

Hypothesis Testing

All hypotheses were tested using PASW 18.0, with a combination of multivariate analysis of variance (MANOVA), due to the three dependent variables, and planned contrasts (Rosenthal and Rosnow, 1991). MANOVA was performed for Hypotheses 1a-c, testing the effect of supplementary cues, and showed significant differences in cell means (*Pillai's Trace*=.21, *F*(3, 510)=44.78, *p*<.001, *partial* eta^2=.21), thus individual ANOVAs were conducted. Hypothesis 1a, which proposed that the use of supplementary cues would improve information selection speed, was supported (*F*(1, 512)=77.29, *p*<.001). Users of the application without any supplementary cues spent an average of 28.40 seconds (*SD*=25.87) between the time a critical incident appeared on their screen and the time they selected it to respond to it, while the users of the applications with supplementary cues had an average response time of 10.85 seconds (*SD*=17.37), or an improvement of almost 62%. Hypothesis 1b proposed that the use of supplementary cues would increase the total number of answered incidents, and was supported with a significant main effect (*F*(1, 512)=6.39, *p*=.01). Users in the conditions without supplementary information cues completed an average of 78.55% of the tasks (*SD*=17.02), while users in the conditions providing additional cues (either one or both) completed on average 82.44% of the tasks (*SD*=14.80). Hypothesis 1c proposed that lower levels of perceived cognitive effort would be associated with the use of supplementary cues, and was also supported. Levels of perceived cognitive effort for those using the application with cues (*M*=2.94, *SD*=1.11) was significantly lower (*F*(1, 512)=80.53, *p*<.001) than that of those using the application version without supplementary cues (*M*=3.96, *SD*=1.22).

The next set of hypotheses proposed how the use of supplementary cues would mitigate the negative effects of time pressure on performance. Before these hypotheses were tested, the negative effects of time pressure on the performance variables were examined. The speed of participants' selection of target information was significantly worse in the high time pressure scenarios (*F*(1, 512)=18.99, *p*<.001), with the users taking more than twice the amount of time to respond to the most critical incidents under high time pressure (*M*=17.73 seconds, *SD*=23.28) than under low time pressure (*M*=8.17 seconds, *SD*=10.66). The percent of answered incidents was significantly worse under high time pressure (*F*(1, 512)=72.84, *p*<.001), with users in the low time pressure condition averaging 91.31% completion of the tasks (*SD*=4.36), while users in the high time pressure condition completing only 78.39% of the tasks (*SD*=16.39). Lastly, users reported significantly higher levels of perceived cognitive effort (*F*(1, 512)=7.88, *p*=.01) in the high time pressure conditions (*M*=3.29, *SD*=1.23) as compared to the low time pressure conditions (*M*=2.94, *SD*=1.16). The specific effects of supplementary cues on these relationships are now discussed.

A MANOVA was performed for Hypotheses 2a-c, the effect of supplementary cues and time pressure, showed significant differences in cell means (cues: *Pillai's Trace*=.12, *F*(3, 508)=22.18, *p*<.001, *partial* eta^2=.12; time pressure: *Pillai's Trace*=.16, *F*(3, 508)=31.85, *p*<.001, *partial eta*^{2}=.16), thus individual ANOVAs with planned contrasts were conducted. Hypothesis 2a proposed that the use of supplementary cues would be more effective at improving dispatcher information selection time in high time pressure scenarios. A planned contrast revealed that the presence of additional cues significantly improved information selection response time under high time pressure (*F*(1, 510)=104.19, *p*<.001, *partial eta*^{2}=.17), while these cues did not improve performance under low time pressure (*F*(1, 510)=0.60, *p*=.44, *partial eta*^{2}=.00), providing support for hypothesis 2a (see Figure4).

Hypothesis 2b proposed that the use of supplementary cues would be more effective at increasing the percentage of answered incidents under higher time pressure than under lower time pressure. A planned contrast revealed that the presence of cues significantly improved overall performance under high time pressure (*F*(1, 510)=11.35, *p*=.00, *partial eta*^{2}=.02), while these cues did not improve performance under low time pressure (*F*(1, 510)=0.00, *p*=.97, *partial eta*^{2}=.00), providing support for hypothesis 2b (see Figure 5).

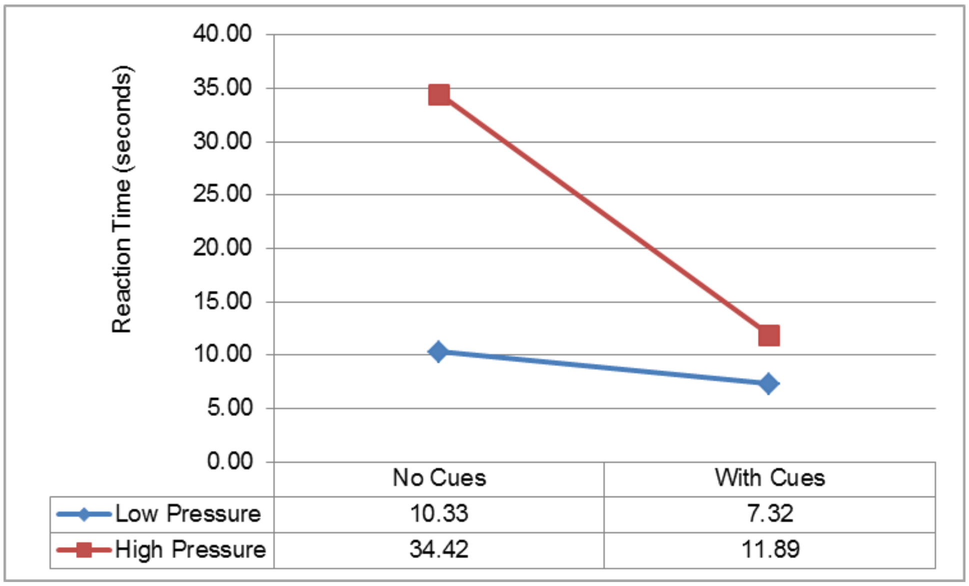

Figure 4: Influence of Supplementary Cues on Information Selection Time under Varied Time Pressure

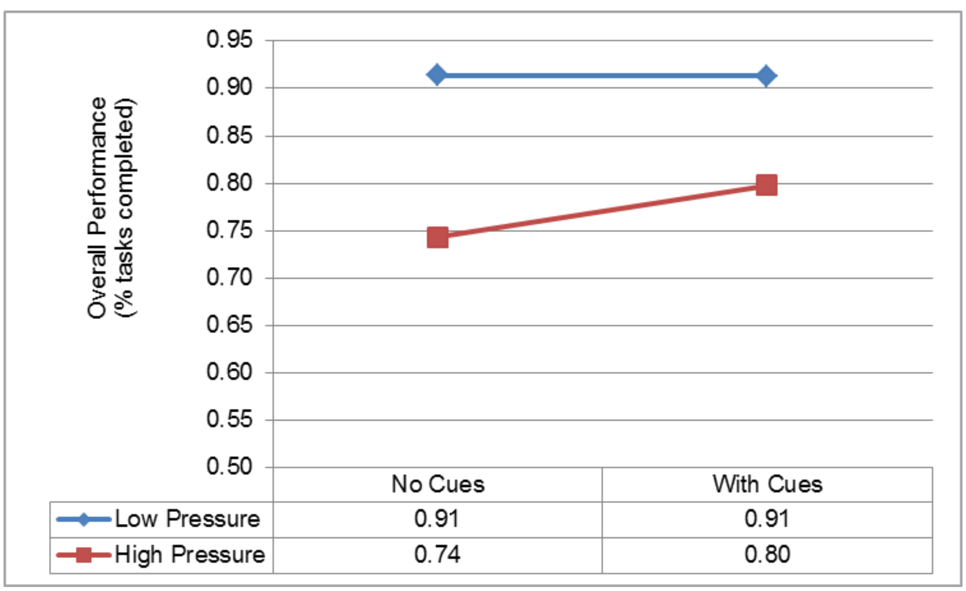

Figure 5: Influence of Supplementary Cues on Overall Performance (Percent of Answered Incidents) under Varied Time Pressure

Hypothesis 2c proposed that the use of supplementary cues would be more effective at decreasing perceived cognitive effort under greater time pressure than under lower time pressure. A planned contrast revealed that the presence of cues significantly decreased perceived cognitive effort under both the high time pressure condition ($F(1, 510)=84.82$, $p<.001$, *partial* $eta^2=.14$) and the low time pressure condition ($F(1, 510)=5.59$, $p=.02$, *partial* $eta^2=.01$), with cues providing a larger effect under high time pressure conditions, providing support for hypothesis 2c (see Figure 6).

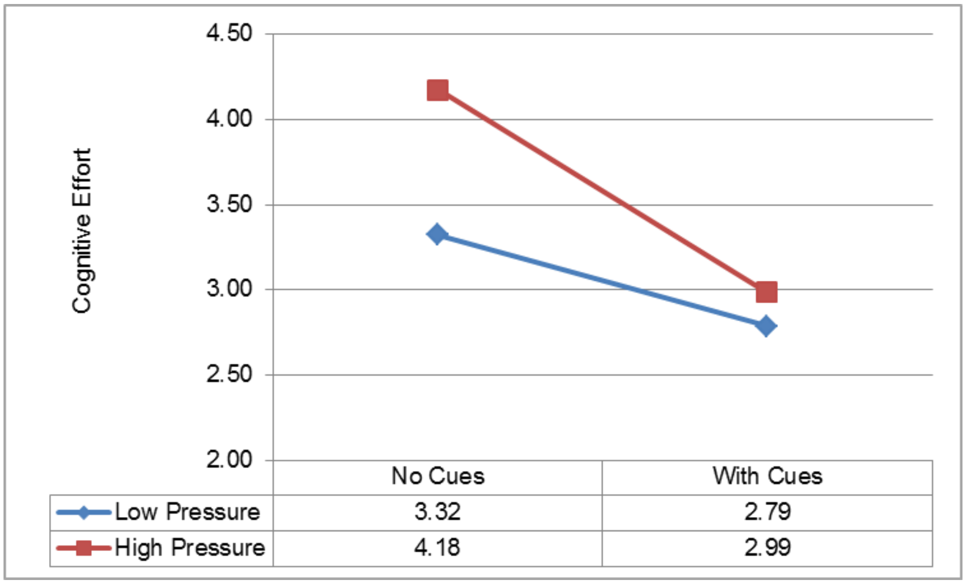

Figure 6: Influence of Supplementary Cues on Perceived Cognitive Effort under Varied Time Pressure

Hypotheses 3a through 3c proposed that in high time pressure situations, the use of two supplementary cues would be more effective than the use of just one cue at improving information selection time (H3a), overall percentage of answered incidents (H3b), and decreasing perceived cognitive effort (H3c). Because these hypotheses were specific to high time pressure, only high time pressure conditions were analyzed for these hypotheses. A MANOVA was performed for Hypotheses 3a-c, the effectiveness of two vs. one cue, and showed significant differences in cell means (*Pillai's Trace*=.05, $F(3, 288)=4.60$, $p=.00$, *partial* $eta^2=.05$), thus individual ANOVAs were conducted. The results revealed that while the presence of two cues was always better than just one cue alone, the difference was statistically significant for only two of the three performance measures. Information selection was significantly improved ($F(1, 290)=7.23$, $p=.01$), however, the overall percentage of answered incidents was not significantly different between the use of two cues or just one cue ($F(1, 290)=2.02$, $p=.16$). Additionally, the use of two cues was significantly better than the use of one cue in decreasing perceived cognitive effort in high time pressure situations, with users reporting a mean of 2.71 out of 7 (*SD*=.96) on the cognitive effort scale using two cues, as compared to 3.12 out of 7 using just one cue (*SD*=1.16) ($F(1, 290)=9.22$, $p=.00$). Hypotheses 3a and 3c are thus supported, while the results do not lend support for hypothesis 3b. Users of the ERS application providing both cues completed an average of 81.68% of the tasks (*SD*=13.99), spending an average of 7.79 seconds (*SD*=12.55) retrieving incidents with the highest priority, while those using the system with either just color-coding or just sorting spent an average of 13.97 seconds (*SD*=20.92) retrieving the highest priority incidents, completing an average of 78.91% of the tasks (*SD*=16.52). Additionally, the participants reported lower levels of cognitive effort when using both cues concurrently. Thus it is appropriate to say that during high time pressure situations, the use of both cues is better able to assist the dispatchers in selecting more important incidents; however, it is only marginally better than the use of either of the cues alone in assisting the dispatchers in answering a greater percentage of incidents.

Hypotheses 4a through 5c proposed that the use of supplementary cues would help mitigate the negative effects of task complexity on performance. Prior to testing these hypotheses, the effects of task complexity on the percentage of incidents answered and response time to critical incidents were examined. Users answered significantly more of the low complexity tasks (*M*=87.35%, *SD*=11.21) than the high complexity tasks (*M*=75.42%, *SD*=16.87; $F(1, 512)=89.21$, $p<.001$). Also, the users' response times were significantly worse when dealing with higher complexity tasks ($F(1, 512)=11.34$, $p<.001$) with the users taking an average of 18.65 seconds (*SD*=22.21) to respond to the highest priority incidents with higher complexity and an average of only 12.36 seconds (*SD*=20.11) when the complexity was low. Lastly, the effect of complexity on cognitive effort did not reach statistical significance ($F(1, 512)=1.94$, $p=.16$), though it did move in the correct direction with higher means of cognitive effort reported for treatments with higher complexity (*M*=3.29, *SD*=1.27) than lower complexity (*M*=3.14, *SD*=1.18). The lack of significance is likely the result of having high time pressure in both complexity conditions, thus users perceived both as being higher in complexity. The specific effects of supplementary cues on performance under varying levels of complexity are now discussed.

A MANOVA was performed for Hypotheses 4a-c, the effect of supplementary cues and task complexity, and showed significant differences in cell means (supplementary cues: *Pillai's Trace*=.21, *F*(3, 508)=45.64, *p*<.001, *partial eta*^{2}=.21; complexity: *Pillai's Trace*=.16, *F*(3, 508)=31.68, *p*<.001, *partial eta*^{2}=.16), thus individual ANOVAs with planned contrasts were conducted. Hypothesis 4a proposed that the use of supplementary cues would be more effective at improving information selection times as the complexity increased from low to high. A planned contrast revealed that the presence of additional cues significantly improved selection times under both levels of complexity (high complexity, *F*(1, 510)=78.16, *p*<.001, *partial eta*^{2}=.13; low complexity, *F*(1, 510)=14.39, *p*<.001, *partial eta*^{2}=.03), however the effect was smaller for lower complexity than for higher complexity, providing support for hypothesis 4a (see Figure 7).

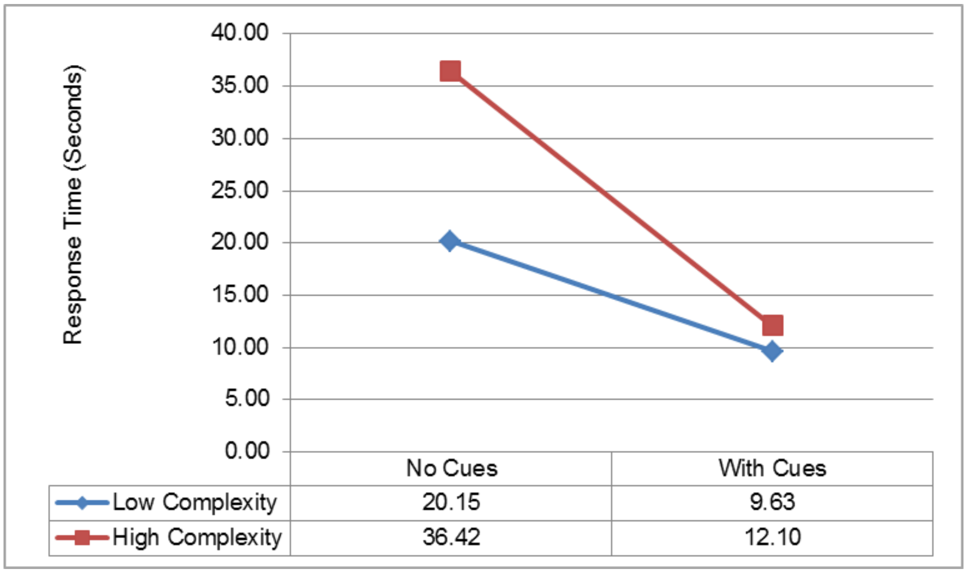

Figure 7: Influence of Supplementary Cues on Information Selection Time under Varying Complexity

Hypothesis 4b proposed that the use of supplementary cues would be more effective at increasing the overall percentage of answered incidents as the complexity increased from low to high. A planned contrast revealed that the presence of additional cues significantly improved overall performance under high complexity (*F*(1, 510)=12.10, *p*<.001, *partial eta*^{2}=.02), while these cues did not improve performance for low complexity treatments (*F*(1, 510)=.06, *p*=.81, *partial eta*^{2}=.00). These results provide support for hypothesis 4b (see Figure 8).

Lastly, hypothesis 4c proposed that the use of supplementary cues would be more effective at decreasing perceived cognitive effort for more complex task than for less complex tasks. The reported levels of perceived cognitive effort were found to be significantly lower for users using supplementary cues when dealing with both low complexity (*F*(1, 510)=23.66, *p*<.001, *partial eta*^{2}=.04) and high complexity tasks (*F*(1, 510)=61.54, *p*<.001, *partial eta*^{2}=.11). The results suggest a greater effect for the high complexity task with mean difference of 1.26 in favor of using additional cues, while in the low complexity condition this mean difference was only 0.78 points (see Figure 9).

Hypotheses 5a through 5c proposed that in high time pressure situations, the use of two supplementary cues would be more effective than the use of just one cue at improving performance for more complex tasks than for tasks of lower complexity. Because these hypotheses were specific to high time pressure, only high time pressure conditions were analyzed for these hypotheses. A MANOVA was performed for Hypotheses 5a-c, the effect of two vs. one cue and complexity, and showed significant differences in cell means for complexity (*Pillai's Trace*=.07, *F*(3, 201)=5.21, *p*=.00, *partial eta*^{2}=.07) and differences approaching significance for two vs. one cue (*Pillai's Trace*=.04, *F*(3, 201)=2.52, *p*=.06, *partial eta*^{2}=.04), thus individual ANOVAs with planned contrasts were conducted. While it initially appeared beneficial to have two supplementary cues rather than just one cue, surprisingly this difference was not significant for any of the outcome variables; thus hypotheses 5a through 5c were not supported. In the low complexity condition, users provided with both cues completed 87.05% of the tasks (*SD*=12.30) as compared to 82.90% (*SD*=13.87) for users with one cue (*F*(1, 203)=1.89, *p*=.17). In the high complexity condition, users provided with both cues completed 77.57% of the tasks (*SD*=13.37), while users with only one cue completed 75.92% of the tasks (*SD*=17.31) (*F*(1, 203)=.28, *p*=.59). Additionally, users provided with both cues responded to high priority incidents in about 5 seconds (*SD*=2.63) in the low complexity condition and 12 seconds (*SD*=20.56) in the high complexity condition, while the users with only 1 cue responded to these critical incidents in about 15 seconds (SD_{low} 27.67, SD_{high}=19.27) at both levels of complexity (Low complexity: *F*(1, 203)=5.35, *p*=.02; High Complexity: *F*(1, 203)=.76, *p*=.39). Lastly, the users reported the perceived cognitive effort with both cues as 2.82 (*SD*=1.11) and with one cue at 3.18 (*SD*=1.09) in the low complexity condition (*F*(1, 203)=2.68, *p*=.10), while in the high complexity condition, perceived cognitive effort was reported as 2.82 (*SD*=0.93) with both cues and 3.10 (*SD*=1.04) with one cue (*F*(1, 203)=1.68, *p*=.20).

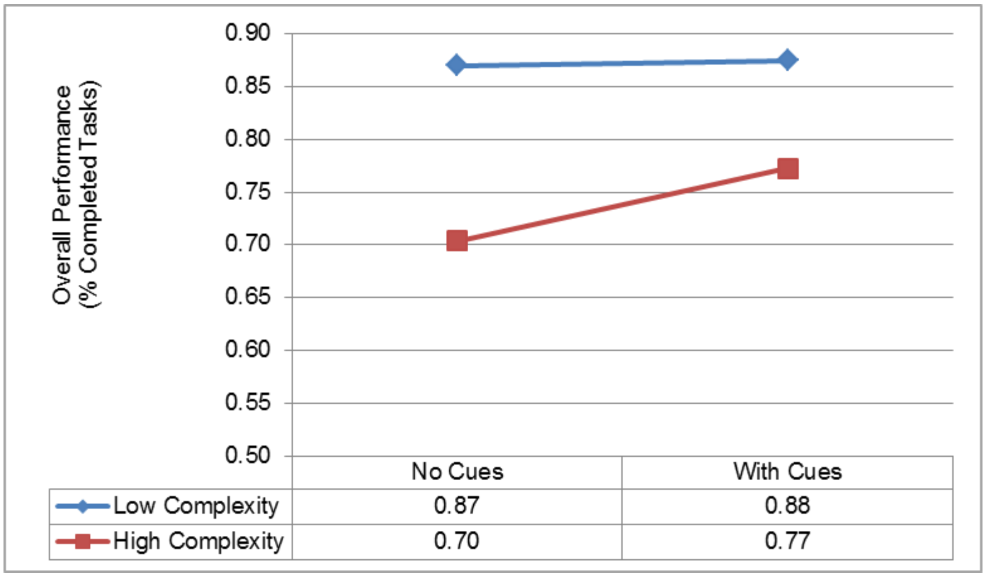

Figure 8: Influence of Supplementary Cues on Overall Performance (Percent of Answered Incidents) under Varying Complexity

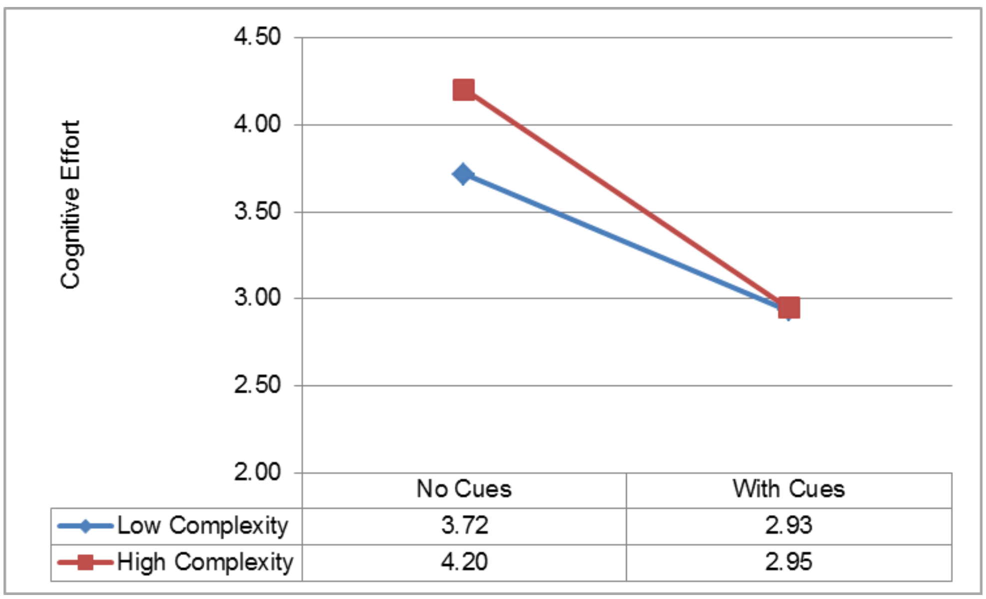

Figure 9: Influence of Supplementary Cues on Cognitive Effort under Varying Complexity

A summary of the hypotheses testing results is provided in Table 2. As shown, the majority of the hypotheses were supported. Further discussion of these results is provided in the next section.

Table 2: Summary of Hypotheses Testing Results

Hypotheses	***Results***
H1a: Designing ERS interfaces with supplementary information cues (color and sorting) will improve dispatcher information selection speed.	Supported
H1b: Designing ERS interfaces with supplementary information cues (color and sorting) will increase the number of answered incidents.	Supported
H1c: Designing ERS interfaces with supplementary cues (color and sorting) will result in lower perceived cognitive effort.	Supported
H2a: The use of supplementary cues will be more effective at improving dispatcher information selection speed under greater time pressure than under lower time pressure.	Supported
H2b: The use of supplementary cues will be more effective at increasing the number of answered incidents under greater time pressure than under lower time pressure.	Supported
H2c: The use of supplementary cues will be more effective at decreasing perceived cognitive effort under greater time pressure than under lower time pressure.	Supported
H3a: In high time pressure situations, the use of two supplementary cues will be more effective at improving dispatcher information selection speed than the use of only one supplementary cue.	Supported
H3b: In high time pressure situations, the use of two supplementary cues will be more effective at increasing the number of answered incidents than the use of only one supplementary cue.	Not Supported
H3c: In high time pressure situations, the use of two supplementary cues will be more effective at decreasing perceived cognitive effort than the use of only one supplementary cue.	Supported
H4a: The use of supplementary cues will be more effective at improving dispatcher information selection speed for more complex tasks than for less complex tasks.	Supported
H4b: The use of supplementary cues will be more effective at increasing the number of answered incidents for more complex tasks than for less complex tasks.	Supported
H4c: The use of supplementary cues will be more effective at decreasing perceived cognitive effort for more complex tasks than for less complex tasks.	Supported
H5a: In high time pressure situations, the use of two supplementary cues will be more effective at improving dispatcher information selection speed for more complex tasks than for less complex tasks.	Not Supported
H5b: In high time pressure situations, the use of two supplementary cues will be more effective at increasing the number of answered incidents for more complex tasks than for less complex tasks.	Not Supported
H5c: In high time pressure situations, the use of two supplementary cues will be more effective at decreasing perceived cognitive effort for more complex tasks than for less complex tasks.	Not Supported

DISCUSSION

In this study, the proposed model of information selection performance aided by supplementary information cues was tested under varying levels of time pressure and task complexity. The results provide support for the overall idea of designing computer interfaces utilizing supplementary cues. More specifically, the results suggest that using supplementary cues in an emergency dispatch interface design can significantly improve dispatchers' performance by allowing them to select critical information faster, increasing their overall percentage of answered incidents reported to the system[5], and decreasing their perceived cognitive effort. Our results further suggest that the use of both cues concurrently (color-coding and information sorting) can offer better information processing and selection performance, but in some cases, the use of just one supplementary cue is sufficient. Furthermore, the use of supplementary cues was more effective at improving information processing performance in higher time pressure situations than in lower time pressure situations, suggesting that the use of these additional cues is especially critical during times when there are significant cognitive demands on the user. Lastly, the cues were more effective at improving users' performance in higher complexity situations; however, the use of both cues was not statistically significantly better than the use of just one of the cues. These relationships deserve future research as the results moved in the proposed direction.

With respect to cue-summation theory, these results may seem surprising. It is important to point out that even though the use of two cues was not statistically significantly better than the use of one supplementary cue in conditions of high time pressure and complexity, this does not suggest a lack of support for the theory. It may be that for this particular task, the use of a second supplementary visuo-spatial cue was not as effective as cues from other modalities, and future research should address different combinations of cues to further our understanding of how to best design these systems. Miller (1957) pointed out that sometimes cues "elicit the same response simultaneously" (p. 78) which may have happened in this case such that their additive benefit was not large enough to be statistically significant beyond the benefits seen from the use of the first supplementary cue. Similar results have also been reported in other studies where subtle task dynamics nullified positive effects of display design (e.g.,Adelman et al., 2004; Padovani and Lansdale, 2003).

The last two questions of the post experimental questionnaire asked the participants to assess what worked well and what did not work well in the experimental dispatch application. Some of the comments were very interesting, as they provide further evidence of the cues helping users' performance or their absence hurting it. For example, one of the participants said the following about the use of color: *"… The colors are a nice way to separate the levels of priority…"* and another one mentioned the following: *"…color-coding the different types of calls made it very easy to determine* *what needed attention first…"* There was also a comment regarding the overall perception of colors *"…very colorful and caught eye (sic), the lay out was effective…"* supporting the reviewed literature suggesting that colors are processed instantly and can be used to influence people's early information processing and information selection.

Interestingly, users also noticed when color was not included and expressed their "dissatisfaction" with the design. The following two comments addressed this issue: *"this application did very well in organization [Note: they did receive a version that included information sorting], preferably having the priorities in color would increase efficiency…"* Another participant noted *"… I thought the new emergencies popping up were good, but the high emergencies should be bright red…"* Lastly, a person using the application with no cues said the following: *"… the application as a whole worked well, but it was not visually helping at all. The system should sort the problems in priority and maybe color code them for a better response time by the dispatcher. It shouldn't have to be all glits (sic) and glamor (sic), but it should be visually helping to the dispatcher…"*

Many of the participants also reflected on the fact that sorting was helpful or missing: one commented that *"…the sorting of each incident in relation to priority was useful and increased my efficiency…"* and another person said that: *"Listing the priority and always keeping the highest priority at the top of the list was helpful…"* There were also some users who suggested that it would have been helpful had the incoming incidents been listed by priority. *"I think it could have been better organized, possibly putting higher priorities at the top of the list automatically, not making the operator switch back and forth looking…"* Similarly, another user said that: *"… when a new emergency pops up, it should automatically resort the list by priority. That way you can get to the real life and death situations first and fast."*

LIMITATIONS

Despite all efforts, this study had some limitations. First, two separate studies were conducted; a full factorial design encompassing both studies was not used in an effort to keep the sample size reasonable. As a result, we did not investigate the combinations of low time pressure and high complexity, and thus could not analyze the full range of interactions between color, information sorting, time pressure, and complexity. In addition, in the sorted treatments, verbal cues (labels) were included above each priority grouping of incidents providing a possible confound to the otherwise spatial cue. The inclusion of these verbal cues should have a minimal effect on the results as verbal cues are symbolic and do not enable associative or parallel processing. Another potential limitation of our study is that four categories of incidents were created, ranging from low to highest priority, and we focused on the highest priority (most critical) incidents. Future research should consider how supplementary cues impact dispatcher performance with less critical incidents. Last, we compared percentage completion rates across tasks of similar and different complexity. Comparisons across different task complexities may be less meaningful and should be further investigated in future research.

Some sample limitations also exist. The results obtained were 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, or older adults, as such individuals may have different visual acumen and sensitivities. Lastly, the data were collected using a student subject pool and the application used was both a simulation and a simplified version of an actual emergency dispatch system. Student subjects can be appropriate when the purpose of a study is controlled theory testing (Calder et al., 1981) and the task is designed to suit their skills and background (Gordon et al., 1986). However, future studies should assess the effectiveness of the proposed design with actual dispatchers preferably using a live system. Additionally, our results may be most applicable to novice users, and future studies need to evaluate whether the observed performance improvements occur regardless of the experience level of the dispatchers. However, some reports state that ordinary individuals were involved in recent crises during early emergency response when trained professionals were not readily available (Sebastian and Bui, 2009), supporting the potential benefits of designing systems for users with a range of expertise to accommodate those high time pressure, high complexity scenarios when all available personnel may be called into action.

IMPLICATIONS

For Researchers

Color-coding has been studied extensively in the information systems literature, and its effects on performance are well documented (e.g., Benbasat and Dexter, 1986; Keller et al., 2006; Yeh and Wickens, 2001). This study extends these findings by providing a theoretical justification for why the use of supplementary cues such as color may improve information processing. In this study, it is proposed that the use of supplementary cues allows users to process information stimuli in parallel when color-coding is used to encode certain information properties, such as priority, in an emergency response context. Additionally, other cues may be beneficial as they allow the users to rely on more automatic information selection, supported by the use of associative processing, as was the case when information was sorted and displayed in a constant location to communicate the desired properties of the information.

For ERS Designers

The results of these two studies suggest that supplementary cues should be used in ERS interface design whenever possible and should be considered for any information system that is used under high time pressure or used for tasks with high complexity. In these experiments, the use of one supplementary cue delivered significant performance improvements, and the use of two cues showed mixed results with several statistically significant findings. In other words, the use of two supplementary cues never had a detrimental effect on performance, and thus should be considered for performance improvement in general interface design to allow for multiple different choices of relieving cognitive effort in pressured or complex situations. Our results also support the views of Padovani and Lansdale (2003) who suggest that choosing the best navigation tool is frustrating, with inconsistent results, and propose that design decisions will hinge upon the specifics of a particular application and context.

For Managers

This research is also informative for managers and users in a position to select systems. The people in charge of these decisions should be cognizant of the design features these systems offer and include the current users of systems in making these purchasing decisions. They should also consider the stability of potential systems and the frequency of updates and new versions being introduced, so that employees do not have to relearn associations with the cues used to help them navigate their information search and selection. Even minor updates to the layout of an interface can change the associations that users have established with location, color, and shape cues. The results also suggest that users' perceived cognitive effort differs widely based on design features, and these perceptions may also have an important effect on other aspects of their quality of work.

FUTURE RESEARCH

This study suggests fruitful areas of research on emergency response systems and for using supplementary cues in general. First, from an emergency response perspective, it is crucial that systems are carefully designed and that these designs are tested to afford dispatchers the use of optimal display design for superior performance. HCI research should be very helpful in establishing a knowledge base of best practices when it comes to designing these systems for optimal performance, and such studies should strive to evaluate various combinations of cues in an effort to reach an optimal solution.

Second, personalization may not be an appropriate option for emergency response systems. While many systems provide users with the ability to personalize interfaces and improve their own performance, little attention has been paid to the unintended consequences of personalized settings (Tam and Ho, 2006). In the area of emergency response systems, this is a significant issue as these systems should be optimized for ultimate performance and integration across multiple users and systems. Some changes have already been made in this regard after the September 11th 2001 terrorist attacks. According to Ball (2008), this crisis revealed that dispatchers from different counties/cities/states were unable to effectively communicate with one another, and efforts have begun to unite the nomenclature (e.g., naming conventions) across these various agencies. In shadowing various dispatchers, interface personalization was observed with several different dispatchers. Future research should weigh the benefits of personalization as compared to the potential integration costs.

A third, more general direction for future research is the examination of the effectiveness of using different visual cues (images, icons, size, shape, etc.) as supplementary cues. Many systems differ in their structure and purpose and thus it is possible that in different contexts, different cues will be more effective at improving decision-makers' performance. Further, different combinations of stimuli should be explored to enhance the benefits of parallel processing. For example, the combination of cues from different modalities (e.g., visual and audio cues), may be very effective at speeding up response times for critical incidents.

Fourth, future research should consider additional boundary conditions under which the use of supplementary cues is most effective, as well as under what circumstances these cues are not effective at improving users' performance. For example, in a moment of overwhelming crisis, there may be a point at which these cues will not help because the majority of the incoming calls will be critical. Knowing these boundary conditions will help developers design systems that can react to these conditions. If we assume that audio cues in combination with visual cues are the most effective, then once a certain threshold is reached, the audio signals may need to be automatically turned off so that they do not create an unintended distraction for the dispatchers. Better understanding of these boundary conditions may also be helpful in optimizing scheduling, because the systems may automatically indicate when backup personnel are necessary.

Lastly, the current study only included participants with good color vision; individuals with color-vision deficiencies were removed from the analysis. Future studies should explore how different supplementary cues could assist these individuals, by identifying which cues (e.g., location, shape, and animation) would serve as the best surrogate for color. Approximately 8% of males and 1% of females have such problems (Walraven, 1992), and thus would benefit from this research. Similarly, other groups with visual impairments, such as deteriorating vision, may have needs that are better served by different visual cues. The results of this study suggest that the use of either color or location is very effective in aiding users' performance, and thus it is possible that people with impairments to their vision may be just as effective in using these types of systems if they are given an appropriate cue or set of cues. The use of different cues, such as animation or audio signals, needs to be evaluated to investigate their ability to enhance users' performance.

CONCLUSION

On April 4, 2009, three officers lost their lives while responding to a call in Pittsburgh, Pennsylvania. After the actions of the responding dispatcher were reviewed, it was discovered that the dispatcher did not relay information about guns being involved to the officers (msnbc.com, 2009). Bob Smith, director of strategic development for the Association of Public-Safety Communications Officials International, based in Daytona Beach, Florida, reportedly said that dispatchers should "never send a response unit to any dangerous or potentially dangerous situation without some advisory about weapons" (msnbc.com, 2009). The operator who handled the call was hired only five months earlier and the relative inexperience may have played a role in this unfortunate event. According to Ball (2008), it takes about nine months for a 911 operator to be fully trained. This study is the first of many that need to be conducted in an effort to address the effectiveness of better design in helping dispatchers in similar situations. The use of supplementary cues, a red color or priority location, may have caught the dispatcher's attention and prevented this omission of information. There are many improvements that can be made to these as well as other systems that can enhance the efficiency and accuracy with which these systems are used.

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[1] Incident reports in all treatments were displayed in chronological order. Sorting was used as an information cue by displaying the incident reports in specific locations sorted by incident priority.

[2] Triage is a process of prioritizing patients based on the severity of their condition and helps in treating patients efficiently when resources are insufficient for all to be treated immediately. The term comes from the French verb trier, meaning to separate, sort, sift or select.

[3] Please note that for some of these codes, different levels of priority can be assigned depending on the severity of the incident. Figure 2 shows a situation in which there is a less serious medical emergency (MEDEM) reported and the assigned color is green, corresponding to a low level of priority. As noted in Appendix A, MEDEM is a special code that can be assigned to incidents ranging from low to highest level of priority depending on the triage results.

[4] Average response time for the highest priority incidents was chosen as the measure of information selection speed for several reasons. Participants were told to respond to the highest priority incidents first (as they would in a real dispatch setting), and the occurrence of highest priority incidents was manipulated to vary the levels of task complexity. Because participants responded to the highest priority incidents first, this category had the least missing data across all treatment conditions. Participants missed increasingly more incidents when moving from highest to the lowest priority incidents across all conditions.

[5] Measures assessing the speed of performance were chosen as this study was specifically designed to test the effects of using supplementary information cues on selection speed in the pre-decision stage. While not hypothesized, we assessed the effects of these design features on response accuracy and found no significant change in the accuracy rate due to the use of cues (.681 with no cues and .700 with cues), suggesting that the cues enabled more efficient processing without negatively affecting the decision-making accuracy in later decision stages.

APPENDIX A: TASK INSTRUCTIONS

Study Overview: WSU Emergency Response is an emergency response system used by 911 dispatchers. Today you will play a role of one of these dispatchers. The calls are being taken by an operator and entered into the system. Your role is to now dispatch these incidents to the appropriate authorities. In the right most corner of the application, you will see a timer. Please dispatch these calls for the full duration of this experiment. We will first look at the application and I will explain to you how it works. Please review the following rules of how to properly dispatch. **Person who can dispatch the most incidents in the shortest amount of time with the greatest accuracy in each section will receive a gift certificate.**

General Rules

1. **Your goal is to answer the incidents with the highest priority first (followed by high, medium, low).**
2. Each incident falls into one of **4 categories based on its priority**. A list of these categories and possible incidents is provided on the next page.
3. To dispatch an incident click on it in the list of incidents and read a more detailed description.
4. Based on the description select the correct number of units to be dispatched and submit your response.
5. I will assign the following number of points for correct answers to determine who wins the gift certificate. **To win, both speed and accuracy will be important.**

Points for Correct Response

Priority Level	***Points Possible***
Highest	40
High	20
Medium	10
Low	5

Rules about Address

Address	***Police Branch***			
	Campus Police	***City Police***	***County Police***	***State***
City & Campus	✓			
City (not campus)		✓		
Colfax			✓	
Colton			✓	
Compton				✓

Type of Incident and Description		***Priority***	***Authority and number of resources dispatched***					
			Campus Police	***City Police***	***County Police***	***State***	***Fire Truck***	***Ambulance***
ALMCOM	Active commercial alarm (no fire)	**High**	2 (based on address)					
	with fire	**High**	2 (based on address)				2 trucks	
ALMRES	Active residential alarm (no fire)	**High**	2 (based on address)					
	with fire	**High**	2 (based on address)				1 trucks	
BLKDIS	Blocking disabled incident	**Medium**	1 (based on address)					
DELTA	Medical emergency with immediate threat of death	**Highest**						1 for every 2 patients
DOMPV	Domestic Problem (verbal)	**Medium**	1 (based on address)					
	w/weapons	**Highest**	2 (based on address)		1 (if City) 3 (if Colfax or Colton)	1		
	w/weapons and injuries	**Highest**				1		1 for every 2 patients
DUI	Driving under the influence	**Medium**	1 (based on address)					
FUP	Follow-up on previous incident or on duty activity	**Low to Highest**	Confirm follow-up or send what is needed					
MAL	Malicious behavior	**Low or Medium**	1 (based on address)					
	Malicious behavior	**High**	2 (based on address)					
MEDEM	Medical emergency	**Low to High**						1 for every 2 patients
PROPFIRE	Property Fire	**High**					3 trucks	
	Property Fire [if suspicious] [if injuries]	**Highest**	[1 if suspicious]				4 trucks	1 for every 2 patients
TRFC	Traffic	**Low**	1 (based on address)					
TRFCOL	Traffic collision (no fire, no injuries)	**Low or Medium**	1 (based on address)					
	with injuries	**High**	2 (based on address)					1 for every 2 patients
	fire and injuries	**Highest**	2 (based on address)			1 (City) 3 (Colfax or Colton)	1 truck	3 trucks

APPENDIX B – MEASURED SCALES

All scales were 7 pt. Likert-type scales with anchors of strongly disagree and strongly agree

Computer Playfulness (adapted from Webster and Martocchio, 1992)

1. When using the Web I am spontaneous.
2. When using the Web I am imaginative.
3. When using the Web I am flexible.
4. When using the Web I am creative.
5. When using the Web I am playful.
6. When using the Web I am original.
7. When using the Web I am inventive.

Perceived Cognitive Effort

1. I felt selecting the report I wanted to dispatch was very time consuming
2. (reverse-coded) Finding the reports I wanted to dispatch took me very little time
3. (reverse-coded) It was easy for me to find the report I wanted to dispatch
4. (reverse-coded) I did not have to pay much attention, when selecting the incident reports, it was automatic

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