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Supervisory-level interruption recovery in time-critical control tasks

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ABSTRACT

This paper investigates the effectiveness of providing interruption recovery assistance in the form of an interactive visual timeline of historical events on a peripheral display in support of team supervision in time-critical settings. As interruptions can have detrimental effects on task performance, particularly in time-critical work environments, there is growing interest in the design of tools to assist people in resuming their pre-interruption activity. A user study was conducted to evaluate the use of an interactive event timeline that provides assistance to human supervisors in time-critical settings. The study was conducted in an experimental platform that emulated a team of operators and a mission commander performing a time-critical unmanned aerial vehicle (UAV) mission. The study results showed that providing interruption assistance enabled people to recover from interruptions faster and more accurately. These results have implications for interface design that could be adopted in similar time-critical environments such as air-traffic control, process control, and first responders.

1. Introduction

Interruptions, a common occurrence in modern workplaces, have been shown to have a wide variety of negative consequences (e.g., Jett and George, 2003). They can result in slower task completion time, increased error rates and additional job stress (e.g., Bailey and Konstan, 2006; Cellier and Eyrolle, 1992; Czerwinski et al., 2000; Van Bergen, 1968). Disruption of work in team-based activities can also lead to coordination problems, including increased time pressure and team member workload (Jett and George, 2003; Reder and Schwab, 1990). Interruptions can have particularly negative effects on personnel working in time-critical environments, such as command and control (C2) settings, as an interruption occurring in these high-risk, information-rich settings may cause personnel to miss critical information directly related to the decision-at-hand. Supervisors in modern work environments are particularly prone to interruptions in the form of "unexpected meetings and conversations" (Jett and George, 2003, p. 494) that interfere with their ongoing tasks (e.g., Mintzberg, 1990). In particular, supervisors in time-critical environments may be impacted by interruptions, especially given the highly collaborative and multitasking nature of these environments (Cooke et al., 2007; Cooke and Gorman, 2006). For example in C2 settings, supervisors not only monitor the mission and make decisions that involve tactical assessment, but are also in charge of monitoring the performance of other personnel. Detecting changes and maintaining situation awareness (SA) of an ongoing mission after an interruption in such complex monitoring tasks often imposes a high working memory load and requires mental calculation (Trafton et al., 2003). To date, however, little research has focused on interruption recovery support for supervisors in C2 settings. Providing such support may help supervisors more effectively resume their previous tasks, which often involves understanding the team's "mission picture" (or "big picture"), which may consequently benefit overall team functioning.

Previous research has investigated operator-level interruption recovery in C2 settings (e.g., Scott et al., 2006; St. John et al., 2005), with a particular focus in assisting operators to "catch up" on changes that occurred in their dynamic task environment while they were attending to an interruption. This research builds on this approach by adapting operator-level interruption recovery methods to account for the informational needs of team supervisors in C2 environments. In particular, this research builds on Scott et al.'s (2006) use of interactive event timelines coupled with discrete event replay to enable unmanned aerial vehicle (UAV) operators to regain SA after interruptions. In that research, selecting an iconic event bookmark from an interactive event timeline

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caused the historical state of the tactical map to be displayed at the time of the event in a separate replay window. This paper extends that previous research by providing an interactive event timeline that highlights team-related events and activities to improve supervisor decision accuracy and timeliness after an interruption.

To further set the context for this work, the paper overviews previous research in the area of time-critical interruption recovery. Next, a representative mission task scenario and experimental platform developed to evaluate the supervisory-level interactive event timeline design concept are introduced, along with the interruption recovery assistance (IRA) tool that reified the interactive event timeline interruption recovery method. A laboratory-based user study is then described that aimed to evaluate the effectiveness of this interruption recovery method on mitigating supervisory-level interruption recovery. Finally, the results of the experiment are detailed and discussed.

2. Background

Over the past decade, there has been a growing interest in understanding the perceptual and cognitive processes involved in regaining the SA after an interruption in dynamic monitoring tasks. In this section, the work of Trafton et al. (2003) to anatomize the interruption process is first discussed. Next, a framework relevant to interruption recovery called Memory for Goal (MFG) model and two interruption recovery techniques, namely the use of *external cues* and *event review*, are reviewed.

2.1. Anatomy of interruptions

Based on a task analysis of different interruption scenarios, Trafton et al. (2003) developed a model to describe the interruption and resumption process. Their model focuses on the temporal process of someone performing a "primary task", becoming aware of an interruption (i.e., the interruption alert), beginning the "secondary task" (i.e., the interruption task), ending the secondary task, and finally, resuming the primary task. The model defines the period of time between the interruption alert and beginning the secondary task as "interruption lag." The period of time between ending the secondary task and resuming the primary task is defined as the "resumption lag" (also referred to as reorientation time (Gillie and Broadbent, 1989) or interruption recovery time (Scott et al., 2006)). Trafton et al.'s research showed that when given an opportunity, people tend to use the interruption lag (e.g., of 8 s in their study), to mentally prepare for the interruption, which in turn, helps to reduce their resumption lag compared to when no interruption lag is provided. Other researchers explain this phenomenon as creating a prospective memory (PM) task in which the interruptee encodes an adequate intention to resume the primary task before orienting to the interruption task (Dodhia and Dismukes, 2009). This model was later expanded by Boehm-Davis and Remington (2009) who further divided the resumption lag into the time to disengage from the interruption task, the time to re-orient to the primary task, and the time to resume the primary task. Re-orienting to the primary task may be problematic since it involves not only a visual re-acquisition, but also memory for important state information (Boehm-Davis and Remington, 2009).

2.2. Memory for Goal (MFG) model

Altmann and Trafton (2002, 2004) proposed a cognitive process model of task resumption in which memory elements of the suspended goals are activated. According to this model, activation of memory elements is subject to decay over time. Therefore, old goals need to undergo a priming process using associative links between the goal and internal (e.g., steps in a procedural task) or external (e.g., environmental) retrieval cues. In subsequent work, Altmann and Trafton (2004) explained how mental preparation, especially via the use of mental or environmental cues during the interruption lag can help an interruptee resume a primary task as predicted by goal-activation theory. In several experiments (Altmann and Trafton, 2004; Trafton et al., 2005), they demonstrated how this theory can predict why providing explicit environmental cues, such as eye-ball icons or very salient arrows that mark the place of someone's recent actions, in a computer interface helps to reduce people's resumption lag following an interruption.

An important assumption that underlies this "preparatory" mitigation technique is that the primary task environment (e.g., computer interface) has not changed while the interruptee is performing the interruption task. However, in many complex task environments, such as command and control, task environments tend to be more dynamic where important situational changes occur in the primary task environment when someone is attending to an interruption. St. John and Smallman (2008) used the MFG model to develop an integrated framework to describe the post-interruption SA recovery in dynamic tasks. According to this framework, during recovery one needs to re-orient to the primary task in order to detect changes in the environment. This additional re-orientation stage (i.e., inferring the situational changes) is cognitively taxing since the interruption degrades the memory of the situation before interruption.

2.3. Change blindness

An important cognitive phenomenon that must be considered when investigating interruption recovery in such environments is change blindness. This phenomenon refers to the fact that people often fail to detect changes within a visual scene, especially when returning to the scene. Supervisory-level command and control tasks are complex monitoring tasks and hence are especially prone to change blindness since detecting mission changes is essential for gaining situation awareness. Previous research shows that interruptions, even for a short time (e.g., screen flickers), may cause the observer to fail to detect substantial changes in the scene or display (e.g., DiVita et al., 2004; Rensink, 2002; Simons and Ambinder, 2005). Simply looking away from a computer screen can also lead to change blindness (e.g., Durlach, 2004; Rensink et al., 1997). In time-critical command and control, many interruptions require a supervisor's visual attention, which in turn can lead to change blindness phenomenon.

One approach to mitigating interruptions in a dynamic task environment prone to change blindness is to use contextual cues to help someone regain their previous context and learn what information they have missed during an interruption. Daniels et al. (2002) implemented an interruption recovery tool using a spoken dialogue interface to mitigate the negative effects of interrupting a military operator while they were performing two monitoring tasks, tracking military logistics requests from deployed ground troops and monitoring their ship's system status. Using verbal queries, operators could ask simple questions regarding the interrupted task such as their status before the interruption (e.g., "where was I?", "what was I last working on?" (Daniels et al., 2002, p. 16)), or request more complex information, such as an audio summary of the task progress since the beginning of the interruption.

2.4. Event review

The majority of the interruption recovery research in dynamic environments has focused on similar "event review" concepts. St. John et al. (2005) investigated a textual event history log called