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Mitigating Supervisory-level Interruptions in Mission Control Operations

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ABSTRACT

This paper introduces a new interruption recovery tool designed to mitigate the negative effects of interruptions on team supervisors in complex, mission control operations. This tool, called the Interruption Recovery Assistance (IRA) tool, provides team supervisors with a visual summary of historical mission changes, in the form of an event timeline. It also enables supervisors to gather more information about a desired event in the context of the primary task display. An initial user study is discussed, which provided mixed results: negative impacts were observed for recovery time, while positive impacts were observed for decision accuracy, especially in complex situations.

Keywords

Human-computer interaction, interface design, interruption recovery, decision support system

INTRODUCTION

The negative impacts of interruptions in modern work environments are well documented. They can increase job stress, task completion times, and error rates in individual task activities (Kirmeyer, 1988; Cellier & Eyrolle, 1992; Czerwinski et al., 2000). Interruptions can also cause coordination problems, work overload, and time pressure in team-based activities (Reder & Schwab, 1990; Jett & George, 2003). The ramifications of an interruption in mission control operations, such as military command and control and emergency response, can be especially costly due to the time and life-critical nature of these operations. These issues have motivated the recent development of software tools, called interruption recovery tools, to help mitigate the effects of interruptions in a variety of task environments. The dynamic and highly collaborative nature of mission control environments, however, introduces particular challenges for the existing approaches to interruption recovery tool design, which often assume that the task environment (e.g., a computer application) a person will attempt to resume post-interruption will remain unchanged during the interruption.

The objective of this research is to develop interruption recovery tools that address the challenges of the dynamic, time-critical, and collaborative task situation inherent to mission control operations. Our current focus is on developing software tools that help mitigate interruption recovery of team supervisors in mission control environments. This initial focus is motivated by the fact that team supervisors are highly susceptible to frequent interruptions (Jett & George, 2003), and, due to the hierarchical organization of many mission control environments, effective supervisory performance is often critical to effective mission performance.

BACKGROUND

Much of the work aimed at helping people recover from interruptions is informed by Trafton and Altman's (2003) model of the interruption process, which focused on the time between an interruption alert and the actual interruption, a period of time called "interruption lag". Altman and Trafton (2004) then proposed that interruption lag could be used as a preparatory stage for interruption and empirically proved that this preparation reduces task resumption time. They also introduced the concept of "resumption lag," also known as reorientation time (Gillie & Broadbent, 1989) or interruption recovery time (Scott et al., 2006), which is the time between the ending of an interruption and resuming the task.

A common interruption recovery approach is to use visual and auditory cues to assist task resumption. Altman and Trafton (2004) found that existence of visual cues such as a cursor where the user left off and eyeball images as an interruption awareness tool in a user interface helps reduce interruption recovery time. The use of verbal cues was studied as an alternative interruption recovery technique. Daniels et al. (2002) implemented an interruption recovery tool using a spoken dialogue interface to mitigate the negative effects of interrupting people while tracking military logistics requests from deployed ground troops. Using verbal queries users can ask interface questions regarding the interrupted task. Another approach involves the "instant replay" of dynamic interface elements (St. John et al., 2005; Scott et al., 2006). St. John et al. (2003; 2005) implemented an instant replay tool called CHEX (Change History Explicit), the goal of which is to give constant awareness of the important changes by populating a table with bookmarks of events in rows.

Scott et al. (2006) examined the impact of different instant replay techniques on interruption recovery in supervisory control of unmanned aerial vehicles (UAVs). Their study investigated an interruption recovery tool provided on a peripheral display in the primary task environment, called the Interruption Assistance Interface (IAI). IAI consists of a replay window, an event timeline, and animation controls. The information on the IAI is dynamically updated when an event happens. They evaluated two versions of the IAI: a "discrete" replay version that allows users to select an icon representing a historical event on an interactive timeline that causes the replay window to show the state of the main task display (a tactical map) at the time the event occurred; and a version of "animated" replay in which users could view an accelerated animated sequence of historical events from a desired time period. Their study found that the IAI's replay tool, especially the "discrete" replay, was beneficial for interruption recovery, particularly when users missed complex system changes.

ASSISTING INTERRUPTION RECOVERY

Based on the results of a requirements analysis, which involved a cognitive task analysis of a representative mission control task scenario (see (Wan et al., 2007) for details), a new interruption recovery tool, called the Interruption Recovery Assistance (IRA) tool, was developed. The IRA tool builds on the previous work in interruption recovery tool design (described above), in particular, it extends the concept of "instant replay" originally investigated by St. John et al. (2003; 2005) and Scott et al. (2006).

In order to evaluate the effectiveness of this design approach for interruption recovery assistance, we incorporated the IRA tool into an existing experimental platform designed to support the investigation of decision and collaborative support tools for futuristic UAV team operations (Scott et al., 2007). The particular task scenario used to evaluate the IRA tool was a ground force protection UAV mission. Before detailing the IRA design for this context, we first provide an overview of the mission control task and the experimental platform.

UAV Mission Control Task and Experimental Platform

In this task scenario, a UAV operations team must secure a large geographic area (the team's area of interest (AOI)) to ensure the safe passage of an important political convoy traveling through the area. During the task, the team must surveil the area for potential threats. If threats are identified, the team must coordinate with an external strike team to engage these hostile contacts before they are within weapons range of the convoy.

In order to secure the AOI, the team utilizes a number of semi-autonomous UAVs. The team must monitor the progress of these UAVs as they provide surveillance of the large AOI and reroute the UAVs from their original surveillance course, as necessary to secure the area. The team may also be required to coordinate with other teams to utilize assets outside of their immediate control to help secure the AOI.

The above mission control task is performed in an experimental laboratory designed to emulate a small command center. In this simulated command center, the UAV team mission commander has access to three large-screen, wall-mounted displays that provide various types of mission-related information: a Map Display, a Mission Status Display, and a Remote Assistance Display (see Figure 1a-c; for a complete description of these displays see Wan et al. (2007)). In order to implement command decisions in the simulated task environment, the mission commander uses a networked tabletPC interface called the Mission Commander Interface (see Figure 1d). In the user study described below, the actions of the UAV operators on the team are simulated as "remote" operators in the task environment: the mission commander monitors the UAV operators' performance, as well as the team's overall mission performance using the large-screen displays. The mission commander can offer threat identification assistance to a "remotely located" operator via the Remote Assistant Display.

In this scenario, interrupting the mission commander can have significant, negative impact on the overall mission. As it is the responsibility of the mission commander to oversee the entire operation, any situation in which a UAV or an operator is underperforming requires the mission commander to rapidly resolve the issue. Thus, if an external interruption occurs (such as providing a report to a superior or taking a phone call), it is very important that the mission commander is quickly brought up to speed on whether any events that occurred during their absence require attention.

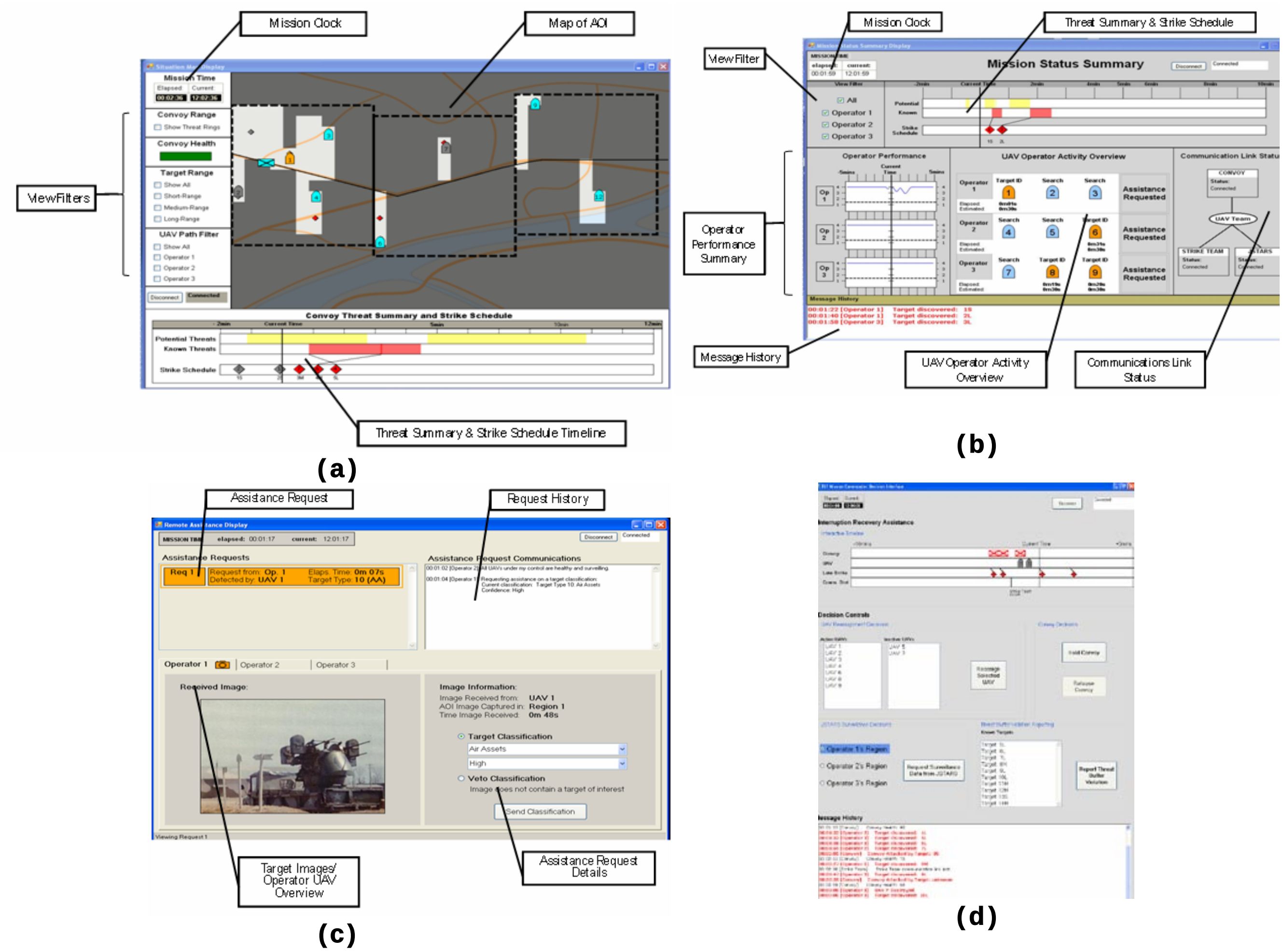

Figure 1. Mission commander displays: (a) Map Display, (b) Mission Status Display, (c) Remote Assistance Display, and (d) Mission Commander Interface (with the IRA timeline). Displays (a)-(c) are large-screen, wall mounted interfaces, while display (d) is a tabletPC interface.

Interruption Recovery Assistance (IRA) Tool for UAV Mission Commanders

To evaluate the IRA tool design concept described above in the context of the UAV mission control task, the IRA interactive event timeline and event "replay" feature were integrated into the UAV Mission Displays shown in Figure 1. In particular, the IRA interactive event timeline was integrated into the Mission Commander Interface secondary task display (Figure 1d), while the event "replay" functionality was integrated into the Map Display (Figure 1a), one of the primary task displays.

Figure 2 shows the details of the IRA timeline. It contains four rows, each displaying event "bookmark" icons of different types of critical mission events: convoy attacks, UAV destroyed, late strikes (i.e., targets that are scheduled to be destroyed after the convoy's current path will cross their weapons range), and communication link status changes. Selecting on an event icon (i.e., an event bookmark) in the IRA timeline

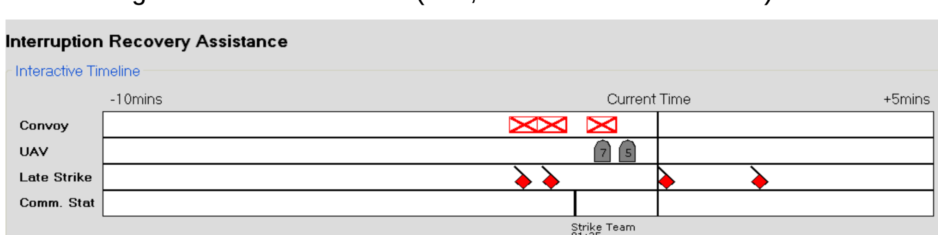

Figure 2. Interruption Recovery Assistance (IRA) interactive event timeline.

results in additional information being displayed on the Map Display, with the exception of the communication link status change events.

As discussed above, when the mission commander selects an event bookmark icon on the IRA timeline that corresponds to the convoy attack, UAV destroyed, or late strike events, additional information appears on the Map Display. This information is displayed for five seconds, and then fades to reveal the current state of the map.

USER STUDY

A user experiment was conducted to evaluate the effectiveness of the IRA tool to facilitate interruption recovery in a time-critical team supervisory task setting. In particular, the study investigated the ability of the IRA tool in reducing the negative impacts of interruptions on recovery time, decision accuracy, and overall task performance of team supervisors in a simulated futuristic UAV team task environment. The details of the study are outlined below.

Participants

Twelve participants, ranging from 18-23 years old, were recruited from the MIT community. Six participants were undergraduate students enrolled in the Reserve Officers' Training Corps (ROTC) program. The six remaining participants included four regular undergraduate students and two recent graduates engaged in research at MIT. Participants randomly assigned to either a control group, who performed that experimental task without the IRA tool, or to the experimental group, who received assistance from the IRA tool. Participants each received $30 remuneration.

Experimental Apparatus

The study took place in the experimental laboratory mentioned above. The laboratory contained three 42-inches (1024x768 pixels), wall-mounted interactive plasma displays. These large displays contained the team supervisory displays (i.e., the Map, Status, and Remote Assistance Displays). A 14.1-inch, Fujitsu tablet PC, containing the Mission Commander Interface, was located on a wooden podium positioned near the large displays. The experimental interfaces were developed in the Microsoft C# .NET programming language. The simulated task environment ran from a simulation computer located just outside the experimental laboratory, next to a viewing glass that enabled the experimenter to monitor participants' mission progress.

Experimental Tasks

Primary Task. For the primary task, each participant was asked to assume the role of the mission commander of the UAV team task described above. The individual UAV operators were simulated as remote participants in the experimental task environment. Potential threats identified by a UAV's ATR system could actually be non-threatening to the mission and should be disregarded by the team during the target identification process. If a (simulated) operator was taking longer than normal during this target identification process, the mission commander could assist the (simulated) operator via the Remote Assistant Display (further details on this process can be found in Wan et al. (2007)). A complete scenario took 15-20 minutes to complete, during which time the participant would experience three one-minute interruptions, as explained below.

Secondary (Interruption) Task. During each experimental trial, participants experienced three interruptions, during which they were asked to complete a secondary task in an adjacent room to the experimental laboratory. This task involved participants completing a paper-based task, provided on a single sheet of paper, ranging from mathematic problems, logic puzzles, and reading and comprehension. Participants were given one minute to complete this task, at the end of which they were asked to return to the primary task, even if they were not finished. If a participant finished early, they were asked to sit and wait until the full one minute had passed. When the participant returned to primary task, they were required to fill out an incident report, in which they were asked to note any changes in the mission status that had occurred in their absence. The purpose of the incident report was to detect any change blindness incidents, as well as assess the general task performance of the participants. Participants were encouraged to complete the incident report as soon as they had stabilized the mission upon their return.

Experimental Design

A 2 (assistance type) x 2 (decision difficulty) mixed experimental design was used, with repeated measures on the decision difficulty factor. The assistance type conditions included: assistance and no assistance. In the assistance condition, participants were provided the IRA tool. In the no assistance condition, participants performed the experimental task without the IRA tool. The decision difficulty conditions included: simple and complex. In the simple condition, there was only one possible decision that could address the mission situation facing the mission commander following an interruption. In the complex condition, several decisions could be made to address the situation; however, one decision most appropriately satisfied the teams' mission objectives.

In order to measure interruption recovery and overall task performance, three main dependent variables were used: interruption recovery time, decision accuracy, and convoy health. Interruption recovery time refers to the time from when a participant returned to the primary task to when they initiate a task action aimed at addressing the situation. Decision accuracy refers to the correctness of decisions made following an interruption. The task actions performed after each interruption were assigned a decision accuracy score, determined as follows: 0 = no action taken; 1 = actions represented a suboptimal decision; 2 = actions represented an optimal decision.

The convoy health score was used to indicate overall task performance. This measure was chosen because the primary objective of the mission was to move the convoy through the terrain as quickly and safely as possible, and the convoy health score was a function of both time (delaying the convoy's progress resulted in reduced health points) and safety (each target attack resulted in further health point reductions).

Procedure

Each participant began by completing an informed consent form and a background questionnaire that gathered participants' demographic information. Next, they completed a computer-based PowerPoint tutorial that outlined the experimental tasks and explained the software interfaces. Participants in the assistance condition were given a tutorial with several additional slides describing the IRA tool.

The participant then completed two practice sessions in the experimental task environment. In the first practice session, they were asked to observe changes of a partial scenario (shortened to only two operator sub-AOIs). Subtle functionalities of the interfaces were explained and the participant was asked questions to test their comprehension. This session took approximately 10 minutes. The second practice session was a simplified, yet complete task scenario in which the participant completed the scenario without direction or assistance from the experimenter. In this session, the participant was interrupted once to complete a secondary task. The goal of this session was to give the participants a chance to acclimate to the interfaces and perform the secondary task and incident report following the interruption. This session took approximately 15 minutes. The participant then completed a full task scenario as the experimental trial. This scenario included the three interruptions discussed above, and took 15 to 20 minutes to complete, depending on skill level. Following the final task scenario, the participant took part in a post-experiment interview to help gather feedback from the participant and information on their interruption recovery strategies. The entire experiment lasted approximately 90 minutes per participant.

RESULTS

In order to elucidate the overall impact of the IRA tool in the UAV mission control task setting, both a quantitative and qualitative analyses of the study data were performed. The following sections summarize the results of these analyses (complete details can be found in Wan et al. (2007)).

Performance Results[1]

Interruption recovery performance refers to how quickly and accurately participants' resumed the primary task following the experimental interruptions. With respect to interruption recovery time, a 2 x 2 repeated measures analysis of variance (ANOVA) comparing assistance type and decision difficulty, blocking for military experience[2], showed no significant differences between either assistance type ($F(1,9)=1.17$, $p=.31$) or decision difficulty ($F(1,10)=1.45$, $p=.26$) levels. However, a marginally significant difference was found for the interaction between assistance type and decision difficulty levels ($F(1,10)=4.48$, $p=.06$), indicating that the IRA tool had some influence on recovery time. In particular, the data indicated a marginally significant difference in interruption recovery time between the military and non-military participants ($F(1,9)=5.08$, $p=.054$). On average, non-military participants recovered from interruptions quicker than military participants (non-military: M=13.4s, SD=5.4s; military: M=20.4s, SD=6.6s). This difference in military and non-military recovery times appears to account for much of the interaction effect between assistance type and decision difficulty. Participants, particularly those with military experience, tended to recover much slower when provided assistance, especially when faced with a complex decision. However, regardless of assistance type, non-military participants tended to take a consistent amount of time to resume the primary task. The box plot in Figure 3 demonstrates this result by showing the median interruption recovery times and the quartiles for each assistance type and decision difficulty levels, for non-military and military participants.

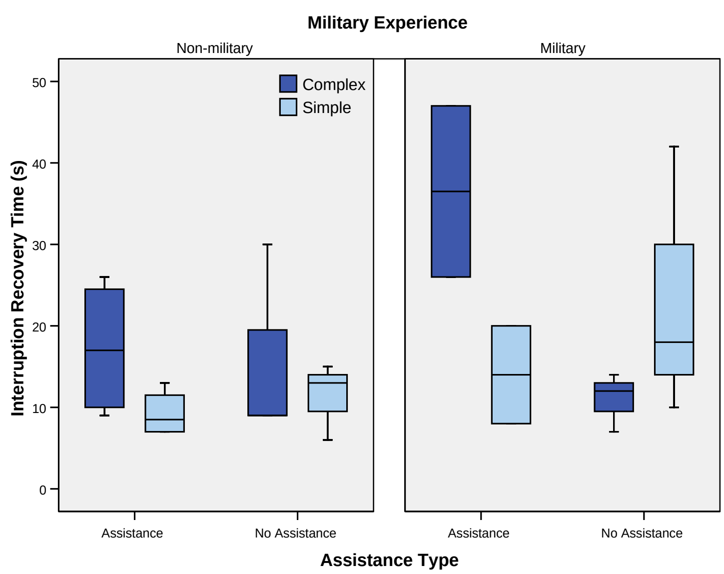

Figure 3. Interruption recovery time by military experience.

These findings are not that surprising given that the use of an external decision aid can be time consuming compared to a mental assessment of a situation (Scott et al., 2006). However, an interruption recovery tool that increases task resumption time may still be effective, as long as the additional time required to use the tool is not excessive and the tool provides sufficient benefits to other aspects of interruption recovery or

[1] Technical difficulties and unexpected user behaviour differences produced unreliable data for interruption three. Thus, data analysis omits performance data for interruption three; convoy health was adjusted to a consistent time between interruptions two and three for the task performance analysis.

[2] For all reported results, $\alpha=0.05$ unless otherwise stated. The data met homogeneity and normality assumptions for all parametric tests.

overall task performance. There was only a 1.25s increase in mean recovery time for non-military participants who were provided assistance compared to those who were not. However, military participants with assistance took, on average, 25s longer to recovery than military participants without assistance. In extremely time-critical task environments, this 25s difference may be excessive, especially if interruptions are frequent, which is often the case for team supervisors. Thus, the additional time could quickly accumulative over the duration of several hours.

With respect to decision accuracy, a Mann-Whitney U test was performed on participants' decision accuracy scores to compare assistance types. This analysis revealed no significant differences (U=12.0, p=.24). However, the data show a trend for improved decision accuracy when participants were provided assistance. This trend is particularly apparent when the impact of assistance types for military and non-military participants faced with a complex decision is examined. Figure 4 shows that non-military participants tended to improve their decision accuracy, and to become as accurate as their military counterparts' when provided with assistance.

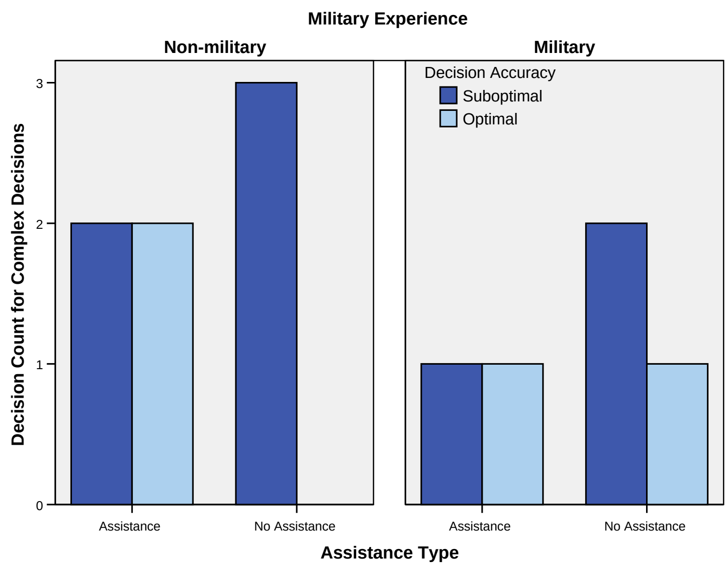

Figure 4. Complex decision accuracy scores by military experience.

Though the statistical analysis of interruption recovery performance is inconclusive, the data suggest that the IRA tool adds slightly to the time aspect of interruption recovery performance, while providing some benefits for decision-making accuracy. The qualitative data analysis presented below discusses which aspects of the IRA tool may have contributed to these mixed results. Also, the varied impact of the IRA tool across the military and non-military populations warrants further investigation to provide further insight into the effects of the IRA tool on supervisory-level interruption recovery in different task domains.

In order to assess the impact of the IRA tool on overall task performance, a one-way ANOVA, blocking for military experience, was performed on the convoy health score. No significant differences were found for either military experience (F(1,9)=0.29, p=.60) or assistance type (F(1,9)=0.58, p=.47). The consistency in participants' convoy heath scores may have resulted from the experimental task scenario being too simplistic and, thus, not requiring sufficiently cognitively demanding decisions, which would increase the potential for task errors and elicit a greater variety in possible convoy health scores between participants. Thus, the use of the IRA tool in more complex task scenarios warrants further investigation.

Qualitative Results

The qualitative data obtained from post-experiment interviews and observer field notes collected during the study provide further insight into the impact and utility of the IRA tool. In particular these data reveal participants' interruption recovery strategies, in relation to both the use of the IRA tool and in general, and the overall usability of the IRA tool.

As reported above, with few exceptions, the presence of the IRA tool had minimal impact on participants' interruption recovery performance. These results are not particularly surprising in light of the fact that most participants in the assistance condition reported that they rarely used the IRA tool. This claim is supported by the computer log file data, which shows that only two people (one military and one non-military) interacted with the IRA timeline. Furthermore, their interactions were limited to replaying "late strike" events. A late strike event was prompted by the scheduling of target strike on a target that would not be destroyed before the convoy, on its currently planned route, would pass within the target's weapons range; thus, making the convoy vulnerable to an attack from that target. Selecting a late strike event on the IRA timeline causes the visual salience of the corresponding target representation on the Map Display's strike schedule, which was often cluttered, to be temporarily increased. While no participant explicitly reported relying on the visual summary provided by the IRA timeline, the fact that military participants with assistance tended to take longer to recover when faced with complex decisions suggests they may have visually examined the IRA timeline to investigate the situation.

However, even when the IRA tool was available, it was not heavily relied on as part of participants' interruption recovery strategies. Only one participant explicitly reported using the IRA tool for interruption recovery. Two alternative interruption recovery strategies were reported in the interviews. The first strategy, reported by five of the twelve participants, involved relying on their memory of the situation, in particular of the status of the map, and comparing the post-interruption situation to their mental image of the pre-interruption state. The second strategy, reported by six participants, involved a combination of the first strategy in addition to mentally noting the time when the interruption occurred to be used to later check for any new status messages on either the Mission Commander Interface or Mission Status Display that appeared during the interruption time. Both of these methods are susceptible to memory loss over time, especially during long interruptions. The latter method can also be cognitively demanding as textual descriptions corresponding to spatial events must be mentally translated to on-screen map events, and could delay decision making.

In summary, the study produced mixed results regarding the effectiveness of the IRA tool in the investigated mission control environment. The statistical analysis indicated that the IRA tool negatively impacted recovery time, while positively impacting decision accuracy, especially in complex task situations. The study results also indicated that the effect of the IRA tool differed across user populations. The study revealed that the IRA tool tended to more positively impact the interruption recovery performance of participants without military experience (i.e., non-ROTC participants). The qualitative data indicated that several usability issues related to the visual and interaction design of the IRA tool hindered its effectiveness. In particular, the location of the IRA event timeline on a tabletPC inhibited its perceived utility as participants found it distracting to look between this display and the main, large-screen interfaces.

CONCLUSIONS

We have presented a novel interface design concept aimed at mitigating the negative impact of supervisory-level interruptions in complex, time-critical mission operations, called the Interruption Recovery Assistance (IRA) tool. We described an initial evaluation of the IRA tool concept in an experimental platform designed to investigate collaborative UAV mission operations. While the results of the user study were inconclusive with regard to the effectiveness of the IRA tool for team supervisors in mission control operations, it did show some positive trends, particularly for helping improve decision accuracy. The study also identified usability issues that likely contributed to the observed increased, rather than desired decrease, in participants' interruption recovery times and to their perceptions of limited tool utility. In particular, the results indicated that integration of the IRA event timeline into the large-screen wall displays, which serve as the primary task displays in the experimental task environment, may help minimize the distraction associated with using the IRA tool during task resumption. We are currently redesigning the IRA tool in the UAV mission control environment to incorporate the feedback from this initial study to improve its efficiency during interruption recovery.

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