MULTIMODAL INFORMATION PRESENTATION IN SUPPORT OF TIMESHARING AND EFFECTIVE INTERRUPTION MANAGEMENT

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Abstract

Operators in complex event-driven domains, such as aviation, face considerable attentional demands. They often need to time-share multiple tasks, and handle interruptions by other human and machine agents who may provide or request information in the interest of coordinating activities. The purpose of this study was to explore possible ways to support these timesharing and interruption management demands more effectively by distributing tasks across various sensory channels and presenting information on the nature of pending tasks to help subjects schedule their various activities. Participants performed a visually demanding air traffic control (ATC) task involving Data Link communication. At times, an interruption task had to be completed, which involved counting a subset of cues that were presented in visual, auditory, or tactile form. One group of subjects automatically received information about the nature of each interruption task whereas a second group was informed only about the presence of an interruption task. Within-subject variables included the modality/priority/frequency of interruption tasks and the workload level of ATC tasks. The results show that subjects delayed the initiation of visual interruption tasks significantly longer than the auditory and tactile tasks, which were less likely to interfere with the visual ATC task. When performed simultaneously with the ATC task, the visual interruption task led to the largest number of errors. Crossmodal interference was lowest when an auditory task was performed in parallel with the ATC task. Overall, findings from this study show that the presentation of concurrent tasks via different sensory channels leads to improved time-sharing performance, possibly due to reduced resource competition and scanning costs. Also, providing information about the nature of the pending interruption task helps participants schedule and manage interruptions more effectively. These findings will be discussed in terms of their implications for the design of multimodal interfaces in support of human-automation coordination.

Introduction

Human operators in complex event-driven domains, such as aviation, often need to perform multiple concurrent tasks in collaboration with other human and machine agents [1, 2, 3, 4]. In the future, the need for collaboration and coordination with machine agents can be expected to increase even further as systems become more autonomous and will need to provide or request information concerning their intentions and actions. This calls for the development of more effective support for time-sharing and interruption management. The present study examines two possible ways to contribute to this goal: a) the distribution of tasks across various sensory channels and b) the presentation of information about the nature of interruption tasks to help operators schedule and coordinate their various activities.

The distribution of tasks across various modalities is suggested by multiple resource theory [5, 6], which is based on the assumption that separate attentional resources are associated with different processing stages, processing codes, and sensory channels. To the extent that tasks are designed to avoid competition for these resources, their joint performance is expected to benefit. For example, if a tracking task that involves the perception and processing of visual spatial information is combined with a concurrent second task that requires speech output of verbal content, then the joint performance of these two tasks should be relatively interference free.

It is important to note that there is an ongoing debate about whether modalities actually represent different central processing resources, or whether the benefits of distributing tasks across sensory channels is related to peripheral factors (such as avoiding visual scanning costs) [7, 8]. However, from an operational perspective, the observed advantages of this approach suggest that it is worth pursuing, independent of the outcome of the debate.

The present study expands on earlier research on multimodal information presentation, which has focused, for the most part, on the visual and auditory channels (e.g., [7, 8, 9, 10]). Only few studies have explored the use and effectiveness of other senses, such as touch (e.g., [11, 12, 13, 14, 15, 16]). The current experiment compares the effectiveness and limitations of all three modalities in the context of data-rich multi-task environments.

The study also looks at the effectiveness of presenting operators with information about the nature of pending tasks to support interruption management. Earlier research suggests that various types of information: a) the source of the interruption [17], b) the urgency of the task, c) the time required to complete the task, and d) the modality of the task [9, 10] can help operators prioritize multiple tasks, schedule them more effectively, avoid crossmodal interference, and thus enhance overall performance. In the present study, one group of subjects automatically received information about the urgency and modality of a pending interruption task. They were also informed about the time remaining to perform the task. A second group of subjects was notified only about the presence of an interruption task. Participants in this group had the option to request the above task-related information if and when it was desired.

Method

Subjects

32 college students (both graduate and undergraduate students) from the Ohio State University participated in this experiment (28 males and 4 females). Their average age was 22.8 years (SD = 3.93). Participation was voluntary, and all subjects were paid $10/hr for their collaboration.

Tasks

Primary Task

Subjects were asked to perform a simulated air traffic control (ATC) task on a desktop computer. Their primary task was to monitor the progress of airplanes and avoid potential conflicts in their sector. They also had to climb and descend aircraft at specific locations and accept and issue handoffs for each plane in a timely manner. Moreover, they were asked to report any unusual events as soon as possible. In particular, they had to detect that one of the planes was deviating from its assigned route.

Interruption Task

While performing the ATC task, subjects had to handle numerous interruption tasks that were presented via the visual, auditory, or tactile modality. They were asked to push the space bar as soon as they detected the initial cue (a red box flashing on the screen) indicating that an interruption task was waiting. Each interruption task involved the presentation of slow and fast pulsing patterns. Subjects were told to count and report the number of fast patterns only. In the case of the visual interruption task, two circles were flashing at the bottom of the screen (see Figure 1); the auditory task involved slow and fast patterns of beeping sounds that were presented via a headset; and the tactile signals were presented in the form of vibrations to subjects' left and right inner wrists. Interruption tasks also varied in terms of their priority (urgent and low priority). In the case of low priority tasks, subjects could wait for up to two minutes before starting the task. In contrast, urgent tasks started immediately after subjects responded to the initial cue or started automatically 5 seconds later if the subject missed the cue.

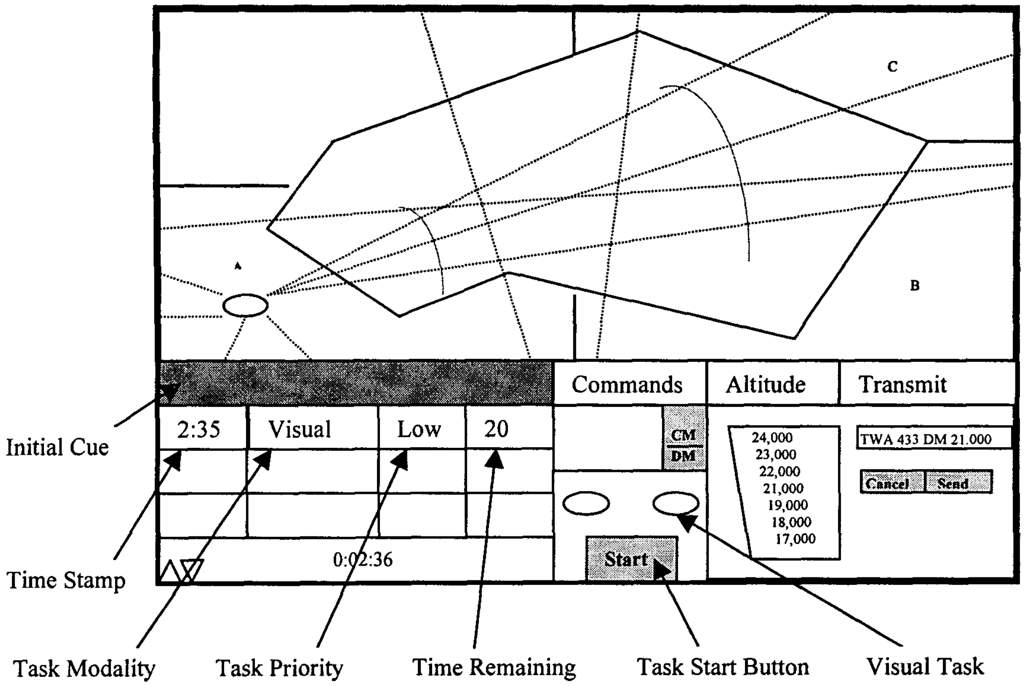

Figure 1. The ATC Simulation And Task-Related Information (Abridged Group)

Once the red box appeared to indicate that an interruption task was waiting, one group of subjects (referred to as the basic group) received information only about the presence of a pending task. They had to click on a particular screen area if they wanted to receive additional information regarding the task modality, urgency, and the time remaining to perform the interruption task. In contrast, the other experimental group (called the abridged group) received this information automatically as soon as the initial cue appeared (see Figure 1).

Procedure

Subjects participated in two sessions, each lasting approximately 1.5 hours. In the first session, subjects received 30 minutes of training on the ATC task. Then, they performed the ATC task on their own for another 20 minutes. Finally, they received 20 minutes of training on handling the different types of interruption tasks in parallel with the ATC task. Only subjects who performed proficiently (made less than 3 mistakes each) in both the ATC task and the interruption tasks during the last 20 minutes of combined training were asked to participate in the actual experiment. The experimental session started with a 10-minute review of the tasks and simulator, followed by a one-hour experimental scenario.

Scenario

In the experimental scenario, subjects first experienced a 10-minute low workload phase (with approximately 8 airplanes in the sector), followed by a 30-minute high workload phase (with approximately 16 airplanes in the sector). The scenario ended with another 20-minute low workload phase.

The scenario also varied in terms of the frequency of interruptions. During high frequency periods, subjects received 6 interruptions (3 urgent tasks and 3 low priority tasks) in each of the three modalities (visual, auditory, and tactile) within 10 minutes; during low frequency periods, subjects experienced the same 6 interruptions in the course of 20 minutes. Workload and interruption frequency were counterbalanced.

In addition, during high workload periods, subjects had to detect and report that an airplane deviated from its course. This deviation occurred a total of three times: once while subjects performed an urgent visual interruption task during the high workload and high interruption frequency phase; a second time when subjects performed an urgent tactile interruption task during the high workload and low interruption frequency phase; and one last time when subjects performed a low priority tactile interruption task during the high workload and low interruption frequency phase.

Experimental Design

Independent Variables

The study employed a mixed factorial design, with the amount of information on the interruption task as the between-subjects variable (basic and abridged groups). The within-subjects variables were interruption task modality (visual, auditory, tactile), interruption task priority (urgent, low), interruption frequency (high, low), and overall ATC workload (high, low).

Dependent Measures

The following indicators of subjects' primary and secondary task performance served as dependent measures in this study (see Table 1).

Table 1. Dependent Measures

ATC Performance

Conflicts
Number of conflicts that occurred (less than 5 miles of separation between aircraft that are within 1,000 feet).

Wrong Command Given (CM/DM)
Number of times a subject intended to climb or descend a plane but pushed the wrong command button.

Wrong Alt. (descend)
Number of times a subject failed to descend planes to the assigned altitude.

Wrong Alt. (handoff)
Number of times a subject failed to climb or descend an airplane to its assigned altitude before it left the sector.

Wrong Sector (handoff)
Number of times a subject handed off an airplane to a wrong sector.

Miss Handoff
Number of times a subject forgot to handoff an airplane to the next sector.

Interruption Task Performance

Interruption Task Performance
Whether a subject reported the correct number of fast patterns.

Concurrent Task Performed
Whether a subject performed the interruption task and the ATC task simultaneously.

Concurrent Task Performance
Whether a subject reported the correct number of fast patterns while performing the ATC task simultaneously.

Low Priority Task Initiation Time
Time between when a subject detected the interruption cue and the start of a low priority task.

Time Until Information Request
Time between when subjects detected the interruption task cue and when they accessed the more detailed information (basic group only).

Detection Time
Time required to detect the interruption cue.

Deviation Reported
Whether a subject reported the deviation of an airplane.

Time Detect Deviation
Time between when a plane deviated from its route and when the subject reported the deviation.

Subject Preference
Subjects' subjective ranking of the three different task modalities.

Results

Given the limited scope of this manuscript, the results section will focus on only a subset of the various dependent measures. In particular, the results of repeated-measures ANOVAs for interruption task performance and task initiation time will be reported. Also, Friedman tests were used to analyze subjects' preferences with respect to the presentation of tasks in the visual, auditory, and tactile modalities.

Interruption Task Performance

Overall, there was no significant main effect of modality on interruption task performance. Subjects in both the basic and the abridged group performed equally well on the visual, auditory, and tactile tasks. There was also no significant main effect of task modality or the amount of task-related information on the performance of urgent tasks. However, a significant interaction was found between the urgency of a task and the amount of task-related information that was presented to the subjects, $F(1,30) = 4.76$, $p = .037$. A paired-sample t test indicates that subjects in the basic group performed significantly better (in terms of correct counts of fast patterns) on low priority tasks ($M = .85$, $SD = .11$) than on urgent ones ($M = .96$, $SD = .065$), $t(15) = 3.13$, $p = .007$ (see Figure 2). No such difference was found for the abridged group.

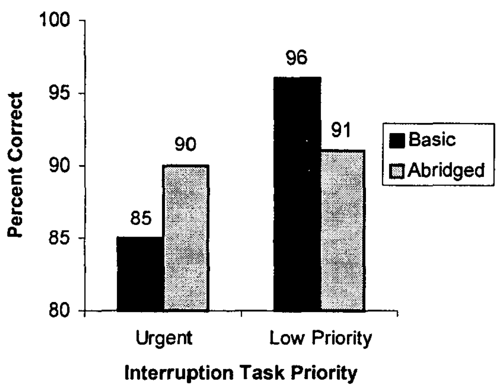

Figure 2. Interruption Task Performance As A Function Of Task Priority And The Amount Of Task-Related Information

Concurrent Task Performance

Next, we analyzed only those cases where subjects performed the air traffic control task and any of the interruption tasks concurrently. 37.5 % of the auditory and 37.1% of the tactile tasks were time-shared but only 16.0% of the visual interruption tasks were performed simultaneously with air traffic control activities (see Figure 3).

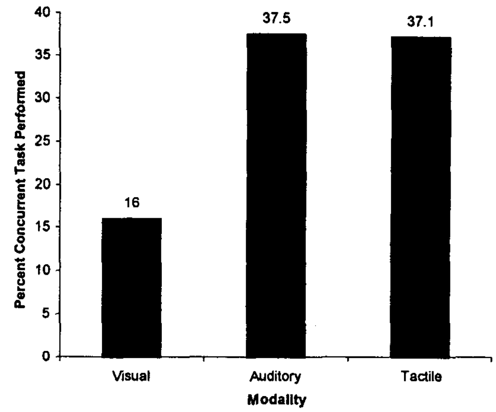

Figure 3. Incidence Of Concurrent Performance Of ATC And Interruption Tasks

A main effect of modality on concurrent task performance was observed, $F(2,62) = 22.03$, $p < .001$ (see Figure 4). The concurrent performance of visual interruption tasks resulted in significantly more incorrect counts than either the auditory or the tactile tasks, which did not differ significantly.

An analysis of cases where subjects performed interruption tasks in isolation did not show a main effect of task modality.

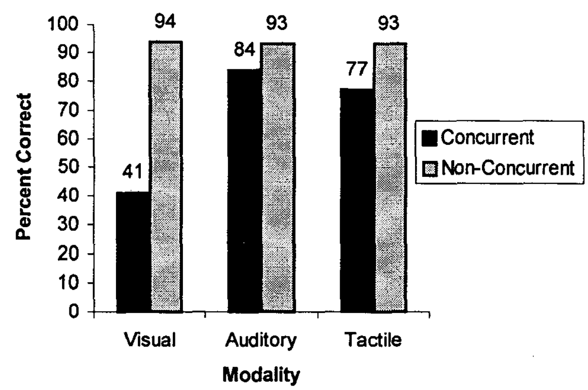

Figure 4. Interruption Task Performance As A Function Of Task Modality And Simultaneity

Time Until Information Request

On average, subjects in the basic group requested task-related information for low priority tasks within 5.9 seconds ($SD = 9.4$) of the initial cue. Note that 61% of all information requests were made within 2 seconds after subjects detected the initial cue (see Figure 5).

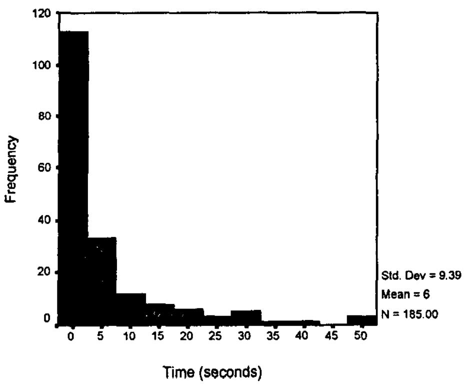

Figure 5. Time Between Detection Of Initial Cue And Request For Additional Information On Low-Priority Tasks (Basic Group Only)

Low Priority Task Initiation Time

In case of low priority tasks, subjects could wait as long as two minutes before initiating the task. Task modality significantly influenced task initiation time, $F(2,46) = 6.738$, $p < .05$. On average, visual interruption tasks were initiated after 22.4 seconds while tactile and auditory tasks were started after 15.7 and 14.7 seconds, respectively (see Figure 6). LSD tests indicate that the visual task initiation time differs significantly from the initiation times for the other two conditions.

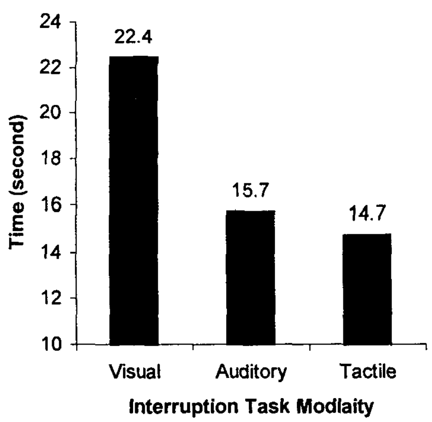

Figure 6. Low Priority Task Initiation Time As A Function Of Interruption Task Modality

Subjects' Preferences

During the debriefing, subjects were asked about their preferences for the three interruption task modalities. Friedman tests show that the auditory modality received a significantly better ranking (Chi-square $(2, N = 32) = 48.6$, $p < .001$) than the tactile modality, which was followed by the visual modality. 31 of the 32 participants in this study considered the visual tasks to be the most difficult to perform.

Discussion

The findings from this study indicate that presenting information about the nature of an interruption (in this case, a pending interruption task) can help operators manage interruptions more effectively and thus improve their overall task performance. Subjects in the abridged group performed equally well on the low priority and the urgent tasks. They automatically and immediately received task-related information in both cases. In contrast, the basic group performed worse than the abridged group in case of urgent tasks when they lacked task-related information. However, their performance improved significantly in case of low priority tasks when they had the opportunity to request information on task modality, urgency, and remaining time before initiating the task (see Figure 2). It is interesting to note that, in 61% of all cases, subjects in the basic group made use of this opportunity within 2 seconds of the initial cue even though it required an additional step and a brief orientation away from their primary task.

Knowledge of task modality, urgency, and remaining time led participants to wait significantly longer before initiating a visual (as compared to an auditory or tactile) interruption task. This suggests that, whenever possible, participants completed their air traffic control tasks first to avoid intramodal interference and scanning costs associated with concurrent performance of the visual (but not the tactile and auditory) interruption task. This interpretation is also supported by the fact that a larger percentage of the auditory and tactile tasks (as compared to the visual tasks) was performed simultaneously with the ATC task (see Figure 3) as well as the fact that participants rated the visual interruption task to be the most difficult one to perform.

Participants' strategy of delaying visual interruption tasks longer than the auditory and tactile tasks (see Figure 6) appears to be an adequate choice given their performance on the three tasks. Performance did not differ significantly between the visual, tactile, and auditory tasks when these tasks were performed in isolation. However, significant performance decrements were observed when subjects performed a visual interruption task in parallel with the visually demanding air traffic control task. In contrast, performance on the auditory and tactile tasks did not change significantly (see Figure 4).

In summary, the findings from this study support the assumption that the distribution of tasks across sensory channels and the presentation of information about the nature of a pending task or interruption are effective means of supporting operators in timesharing and managing multiple attentional demands. These demands can be expected to increase further as more and more highly autonomous systems and associated monitoring and coordination tasks are introduced to highly complex dynamic domains. Follow-up studies will be conducted to address a number of unanswered questions and challenges. For example, the compatibility between tasks and modalities needs to be examined in more detail. The feasibility and value of providing more or different types of information on the nature of tasks and interruptions need to be explored. And the ability to support more complex situations involving multiple concurrent interruptions and multiple modalities needs to be examined.

Acknowledgment

The work reported in this manuscript was supported, in part, by a CAREER award from the National Science Foundation (grant # IIS-9996448; Technical monitor: Ephraim Glinert). We would also like to thank the pilots who participated in this experiment and Sagar Reddy for creating the air traffic control simulation.

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