SUPPORTING TIMESHARING AND INTERRUPTION MANAGEMENT THROUGH MULTIMODAL INFORMATION PRESENTATION

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Operators in complex event-driven domains often need to perform multiple concurrent tasks and handle competing attentional demands, such as interruptions by other human or machine agents. This study examined the effectiveness of distributing tasks across various sensory channels and presenting information on the nature of an interruption task to support timesharing and attention management. Participants performed a visually demanding simulated Air Traffic Control (ATC) task involving Data Link communication. At times, an interruption task was introduced, which consisted of counting subsets of signals that were presented in visual, auditory, or tactile form. Half of the subjects automatically received information on the modality and urgency of these pending interruption tasks whereas the other participants had the option to request this information. Within-subject variables in this study included ATC-related workload and the frequency and priority of interruption tasks. High-priority tasks had to be performed immediately whereas low-priority tasks could be delayed for up to two minutes. The results show that information about the nature of pending tasks supported participants in scheduling and timesharing more effectively. They were able to avoid intramodal interference and scanning costs associated with performing the ATC task concurrently with a visual interruption task. Crossmodal interference was lowest for auditory interruption tasks. Overall, these findings illustrate the benefits of multimodal information presentation and more informative interruption signals.

INTRODUCTION

Human operators in many complex event-driven domains need to handle competing attentional demands and perform multiple concurrent tasks in collaboration with other human and machine agents. They could benefit considerably from more effective support of attention allocation for interruption management and timesharing. One possible way of supporting timesharing has been suggested by multiple resource theory (Wickens, 1984), which proposes that different processing stages, processing codes, and possibly different sensory channels (such as vision, hearing, or touch) are associated with separate attentional resources. Recent studies have confirmed that the concurrent performance of two tasks benefits if these tasks are presented via different modalities (e.g., Wickens, Sandry, & Vidulich, 1983; Latorella, 1998). There is an ongoing debate about whether these benefits are due to peripheral factors (such as avoiding visual scanning costs), or whether modalities actually represent different central processing resources (see Wickens & Liu, 1988; Spence & Driver, 1997). In either case, from an operational perspective, the observed advantages of this approach suggest that it is worth investigating and pursuing further. In particular, earlier research on crossmodal information presentation has focused almost exclusively on the visual and auditory modalities. Very few studies have examined the use and effectiveness of other senses, such as touch (e.g., Suri et al, 1998; Sklar & Sarter, 1999). To help fill this gap, the present study examines the use of both visual, auditory, and tactile task presentation for supporting timesharing.

Not all tasks need to be timeshared. In some cases, it is possible and advantageous to delay a task or the response to some interruption. However, operators often lack the necessary information to determine whether these events warrant an immediate attention shift or can be postponed. The present study explores the effectiveness of presenting operators with partial information about the nature of a pending task (in particular, task urgency and modality, and the time remaining to perform a task) to help them schedule their activities more effectively and avoid interference among tasks.

METHOD

Subjects

The participants in this study were 32 students at the Ohio State University (28 men and 4 women). Their average age was 22.78 years (SD = 3.93). Participation was voluntary, and subjects were paid for their cooperation. They were randomly assigned to one of two experimental groups, which differed with respect to the availability of task-related information [for details, see section on "Interruption Task"].

Tasks

Primary Task. Subjects were asked to perform a simulated air traffic control (ATC) task that was run on a Pentium III desktop computer. Their primary duty was to avoid potential conflicts between aircraft in their sector. They also had to accept and initiate handoffs from/to other sectors, and climb or descend each aircraft under their control to predefined altitudes in a timely manner. Moreover, they were asked to report any unusual events, such as a plane deviating from its route, as quickly as possible.

Interruption Task. In parallel with the simulated ATC task, subjects had to handle numerous interruption tasks that were presented in the visual, auditory, or tactile modality. A pending task was indicated by a visual cue (a red flashing box on the screen). Subjects were asked to push the space bar on their keyboard as soon as they noticed the initial cue. Tasks consisted of slow and fast pulsing patterns of a visual object (two circles flashing on the screen) (see Figure 1), an auditory sound (beeps from a headset), or a tactile signal (vibrations from tactors that subjects were wearing on their inner wrists). Subjects were asked to count and announce the number of fast patterns only. Interruption tasks also varied in terms of their priority. Urgent tasks started immediately once the subject responded to the initial cue, or they automatically started after 5 seconds if the subject missed the cue. In the case of low priority tasks, subjects could delay task initiation for up to two minutes. A third variable in this experiment was the amount of information that subjects received concerning the nature of the interruption task. In the basic group, only a time stamp appeared on the screen to inform subjects that a task is waiting. Subjects had to click on the area around the time stamp to request additional information about task modality, priority, and the time remaining for performing the task. In contrast, subjects in the so-called "abridged group" automatically received this information as soon as an initial cue appeared.

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 different types of interruption tasks in parallel with the ongoing ATC task. The second session included a 10-minute review of the ATC task and the interruption tasks, followed by a one-hour experiment. Only subjects who performed proficiently (made less

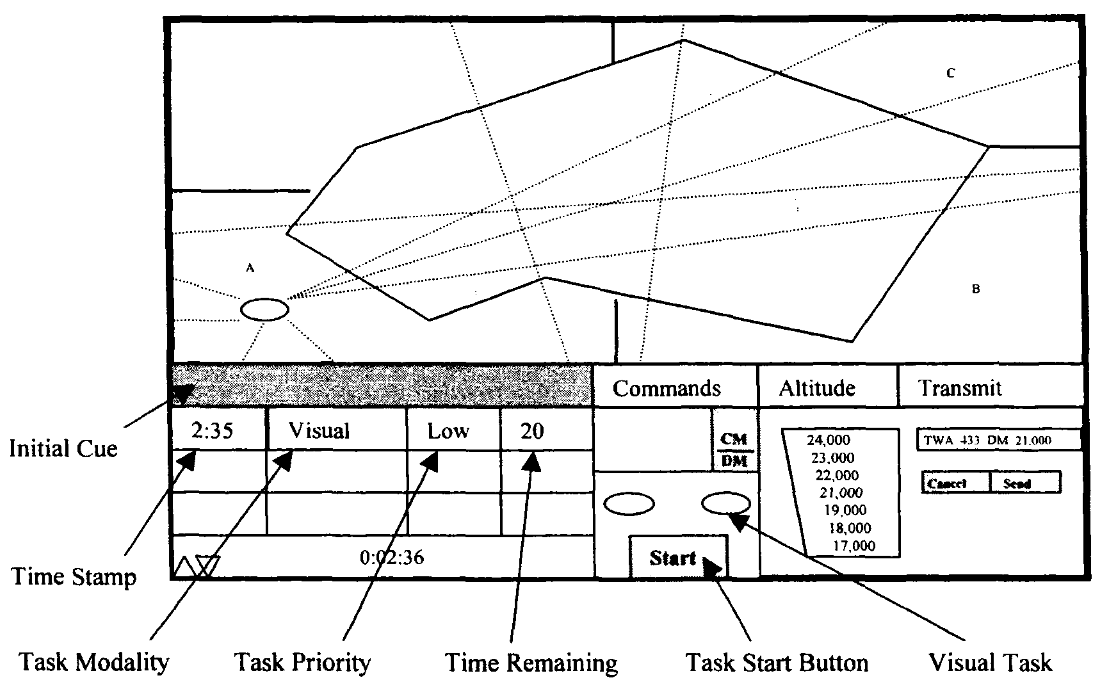

Figure 1. The ATC simulation and task-related information (abridged group)

than 3 mistakes each) in both the ATC task and the interruption tasks during the last 20 minutes of combined training participated in the actual experiment.

Scenario

The experimental scenario consisted of 4 different phases (see Table 1) that varied in terms of workload and interruption frequency. During the high workload period, subjects were working 16 airplanes in their sector, which resulted in higher monitoring demands and the need for more control inputs than the low workload period in which they were controlling 8 airplanes only.

Table 1. Experimental Scenario

Phase	Duration (minutes)	Workload	Interruption Frequency
LH	10	L(ow)	H(igh)
HH	10	H(igh)	H(igh)
HL	20	H(igh)	L(ow)
LL	20	L(ow)	L(ow)

Subjects received 1 urgent and 1 low priority task in each of the three modalities (visual, auditory, and tactile) during each of the four phases. The high and low interruption frequency phases lasted for 10 and 20 minutes, respectively. Workload and interruption frequency were counterbalanced. In addition, during the high workload periods, subjects had to detect and report three times that an airplane deviated from its course.

Experimental Design

Independent Variables. This study employed a mixed design where the amount of information given to subjects (basic, abridged) was the between-subject variable. Interruption task modality (visual, auditory, tactile), task priority (urgent, low), workload (high, low), and interruption frequency (high, low) were the four within-subject variables.

Dependent Measures. The following table shows a subset of the dependent measures in this study (see Table 2).

Table 2. Dependent Measures

Interruption Task Performance	Whether a subject reported the correct number of fast patterns.
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).
Subject Preference	Subjects' subjective ranking of the three different task modalities.

RESULTS

Given the limited scope of this paper, only a selection of our findings can be presented. We will focus on the task initiation times and subjects' performance on the interruption tasks as a function of different modalities and different levels of workload. Repeated-measures ANOVAs were conducted on these data, and Friedman tests were used to analyze subjects' ratings of the three different task modalities. Note that, in 61% of the low-priority tasks, subjects in the basic group requested task-related information within 2 seconds of detecting the initial cue. Therefore, we combined the data for subjects in the basic and the abridged groups.

Interruption Task Performance

Subjects performed significantly better on low priority interruption tasks, compared to urgent tasks, $F(1,30) = 7.013$, $p = .013$. They correctly counted the number of fast patterns in 93.4% of the low-priority tasks as opposed to 87.5% of the urgent tasks (see Figure 2). There was no main effect of the task modality.

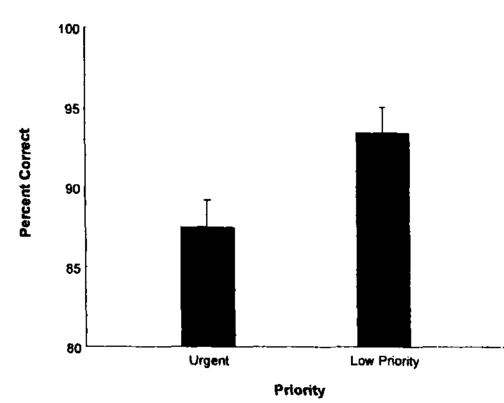

Figure 2. Interruption task performance as a function of task priority

Low Priority Task Performance

Next, we analyzed only those cases where subjects performed a low priority interruption task, which allowed for delayed task initiation. There was a significant main effect of simultaneity, $F(1,31) = 51.4$, $p < .001$. Subjects' performance was better when they engaged in a low-priority interruption task alone (95% correct counts on interruption tasks), compared to their performance when they handled the ATC and the interruption task concurrently (54% correct counts). A significant interaction was found between simultaneity and task modality, $F(2,62) = 11.7$, $p < .001$. LSD tests show that the concurrent performance of the auditory interruption task (78% correct counts) resulted in significantly more correct counts than the tactile task (57% correct counts), which was significantly better than the visual task (27% correct counts) (see Figure 3).

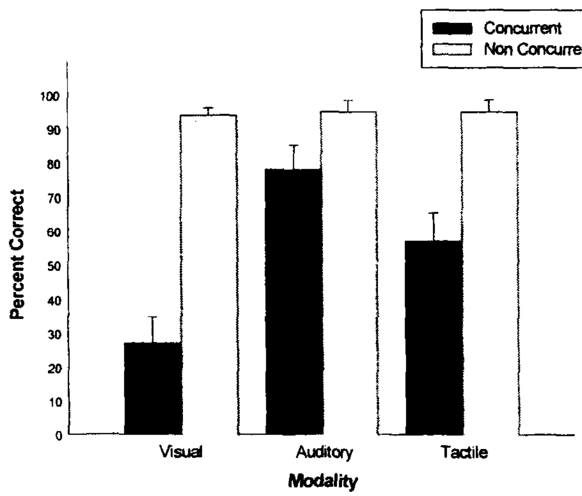

Figure 3. Interruption task performance as a function of task modality and simultaneity

Low Priority Task Initiation Time

There was a significant main effect for task modality. 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, $F(2,46) = 6.738$, $p < .01$ (see Figure 4). LSD tests indicate that the visual task initiation time differs significantly from both the tactile and auditory modalities.

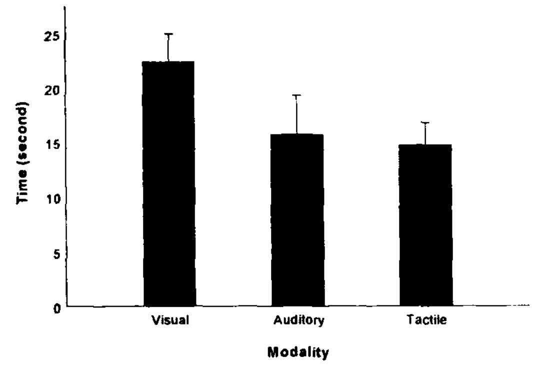

Figure 4. Low priority task initiation time as a function of interruption task modality

A significant interaction between task modality and workload combined with the interruption frequency was found, $F(6, 138) = 5.36$, $p = .001$, such that high workload coupled with high interruption frequency led to the slowest initiation of an interruption task (average of 23.8 seconds) whereas the average delay in low workload low interruption frequency conditions was only 11.3 seconds, $F(3,69) = 8.766$, $p < .001$. A more detailed analysis of the data shows that this result is due to subjects' response to visual interruption tasks. On average, subjects waited 37.7 seconds before starting the visual tasks in this condition (see Figure 5).

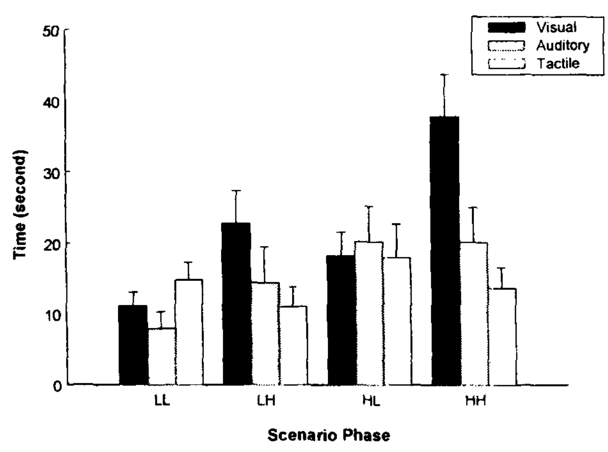

Figure 5. Low priority task initiation time as a function of scenario phase and task modality

Subjects' Preferences

Subjects were asked to rate their preference for the three interruption task modalities. Friedman tests show that auditory interruption tasks were rated easiest (Chi-square $(2, N = 32) = 48.6$, $p < .001$), followed by tactile, and then visual tasks, which 31 of the 32 participants in this study considered to be the most difficult.

DISCUSSION

The findings from this study confirm that the availability of (partial) information on the nature of an interruption supports operators in managing their various tasks and activities more effectively. In the case of low-priority tasks, it allowed subjects to decide whether to complete their ATC tasks first and thus avoid competition between the ATC and a pending interruption task. This is reflected by the observed better task performance in case of low-priority tasks, compared to the urgent tasks where subjects had no control over task initiation. In particular, subjects delayed the initiation of visual interruption tasks the longest (see Figures 4 and 5), which suggests that they were trying to avoid intramodal interference and scanning costs associated with the concurrent performance of two visual tasks. This explanation is supported by the fact that, during the debriefing, they rated the concurrent performance of two visual tasks as being most difficult. Our explanation and their assessments are supported, in turn, by the performance data, which show the largest number of incorrect counts when a visual interruption task was performed concurrently with the ATC task (see Figure 3).

The perceived value of interruption-related information is reflected also by the fact that, in 61% of the low-priority tasks (which allowed for a 2-minute delay), subjects in the basic group requested the information within 2 seconds of detecting the initial cue. In 35% of these tasks, they even requested the information within 1 second. They did so even though this request required a brief orientation away from their primary task.

Participants performed equally well on the visual, tactile, and auditory tasks when these tasks were handled in isolation. Performance on all three tasks suffered when they were handled concurrently with the ATC task. This cost was smallest for auditory interruption tasks, followed by tactile and then visual tasks. This finding is important since very few studies to date have compared performance under all three crossmodal conditions. Most studies have examined interference between two modalities only - the visual and auditory channels.

In conclusion, the findings from this study confirm earlier research (e.g., Latorella, 1999), which has shown that providing operators with partial information on the nature of a pending task or an interruption helps them coordinate multiple activities in a more effective manner. This has important implications for improving the design of today's alarm and communication systems, which tend to alert operators only to the fact that something may require their attention. These systems often fail to provide more detailed information to support operators in deciding whether immediate shifts in attention are warranted and desirable, or whether an ongoing task/line of reasoning should be completed first.

The study also confirms that presenting concurrent tasks via different sensory channels leads to improved timesharing, possibly due to reduced resource competition. In particular, our findings expand on earlier research by comparing performance in three modalities – vision, hearing, and touch. Follow-up studies will be conducted to explore the feasibility and value of providing more or different types of information on the nature of tasks and interruptions, and the ability to support more complex situations involving multiple concurrent interruptions and multiple modalities.

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REFERENCES

Latorella, K. A. (1998). Effects of Modality on Interrupted Flight Deck Performance: Implications for DataLink. *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*, pp. 87-91.

Latorella, K. A. (1999). *Investigating Interruptions: Implications for Flightdeck Performance*. NASA/TM-1999-209707. Hampton, Virginia.

Sarter, N. B., & Woods, D. D. (1992). Pilot Interaction with Cockpit Automation: Operation Experiences with the Flight Management System. *International Journal of Aviation Psychology, 2(4)*, 303-321.

Sarter, N. B., & Woods, D. D. (1994). Pilot Interaction with Automation II: An Experimental Study of Pilots' Model and Awareness of the Flight Management System. *International Journal of Aviation Psychology, 4(1)*, 1-28.

Sarter, N. B., & Woods, D. D. (1997). Team Play with a Powerful and Independent Agent: Operational Experiences and Automation Surprise on the Airbus A-320. *Human Factors, 39(4)*, 553-569.

Sarter, N. B., & Woods, D. D. (2000). Team Play with a Powerful and Independent Agent: A Full-Mission Simulation Study. *Human Factors, 42(3)*, 390-402.

Sklar, A. E., & Sarter, N. B. (1999). Good Vibrations: The Use of Tactile Feedback in Support of Mode Awareness on Advanced Technology Aircraft. *Human Factors, 41(4)*, 543-552.

Spence, C. & Driver, J. (1997). Cross-Modal Links in Attention between Audition, Vision, and Touch: Implications for Interface Design. *International Journal of Cognitive Ergonomics, 1(4)*, 351-373.

Suri, N., Braden McGrath, B., Raj, A. K., Perry, J. F., Carff, R.W., Mitrovich. T. S., &. Rupert, A. H. (1998), Tactile Situation Awareness System. In Boy, G., Graeber, C., Robert, J. M. (Eds.), *HCI-Aero '98 International Conference on Human Computer Interaction in Aeronautics* (pp. 97-102), Montreal, Quebec.

Wickens, C. D., Sandry, D. L., & Vidulich, M. (1983). Compatibility and Resource Competition between Modalities of Input, Output, and Central Processing. *Human Factors 25(2)*, 227-248.

Wickens, C. D. (1984). Processing Resources in Attention, In R. Parasuraman & R. Davies (Eds.), *Varieties of Attention* (pp. 63-101). Orlando, FL, Academic Press.

Wickens, C. D. & Liu, Y. (1988). Codes and Modalities in Multiple Resources: A Success and Qualification. *Human Factors, 30(5)*, 599-616.