Factors Affecting Task Management in Aviation

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Objective: We investigated the influence of ongoing task display "compellingness" on attention allocation patterns and assessed its interaction with interrupting task salience and importance. **Background:** There are some concerns that the compellingness of flight deck tunnel displays renders the task they support more resistant to interruptions, thus preventing the pilot from noticing cues signaling the need to divert attention to other tasks. **Methods:** Forty pilots flew three curved approaches in a high-fidelity simulation using a synthetic vision system (SVS) display. In addition to the primary task of flying, during the last approach they were required to select the approach path on the basis of environmental information concerning weather. The display layout supporting the primary flight task (tunnel vs. baseline display), the nature of the cue signaling the need to divert attention to the path selection task (visual vs. auditory-visual cue), and the cost of not performing the secondary task were manipulated to investigate their influence on task prioritization. **Results:** The modality and priority of the cue affected the frequency of the switch to the secondary task. Furthermore, pilots flying with a tunnel display were more likely to detect the change in the weather and were easily interrupted by the secondary task when priority was high. **Conclusion:** Our results suggest that some of the concerns regarding the negative consequences of the compelling nature of the tunnel display may not be as pronounced as thought. **Applications:** This study highlights the utility of the tunnel display in improving flight safety.

INTRODUCTION

Issues of task management have gained considerable prominence in research in many complex multitask domains (e.g., Liao & Moray, 1993; Raby & Wickens, 1994). Such issues have recently been joined by a closely related body of research on interruption management (see McFarlane & Latorella, 2002, for a review) and a more basic psychological literature on task switching and executive control (e.g., Monsell, 2003; Rubinstein, Meyer, & Evans, 2001). In many respects the airplane cockpit is the prototypical multitask environment in which issues of good and poor task management have important safety implications (Chou, Madhavan, & Funk, 1996; Dismukes, Loukopoulos, & Jobe, 2001; Funk, 1991). For example, Chou et al. (1996) reported that 23% of aircraft accidents that occurred during a 10-year period had poor task management as one of their underlying causes.

One way to think about the findings of task management research is in terms of *ongoing task* (OT) and *interrupting task* (IT) interactions. For instance, one goal of task management research should be to reveal generalizable properties of an OT that either invite or resist interruptions and those properties of an IT that make such interruptions more or less likely (or more or less immediate).

Recent research efforts have focused on the properties of the OT that may invite or resist interruptions. Of particular interest to us in the current research is the "compellingness" or "engagement" of the OT as a determinant of its interruptability. Although such a label invites a danger of circularity (tasks are called compelling if they resist interruptions, and compelling tasks

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are said to resist interruptions), such circularity can be mitigated to the extent that there is a set of compelling tasks or display features that may be defined a priori and independently of their behavioral consequences. Of direct relevance to the current research, and to advanced aviation in general, is the potential compellingness of flight deck tunnel displays, which are characteristic of the so-called synthetic vision systems (SVSs; Prinzel et al., 2004). There are indeed some concerns that their high level of realism may cause pilots to become tunneled on them, at the expense of monitoring the outside world (Society of Automotive Engineers, 2005). Indeed, a deep analysis of pilot detection performance of "off-normal," unusual events presented in the outside world, but not visible on the SVS displays, suggests that such concerns have some statistical basis (Thomas & Wickens, 2004; Wickens, 2005). Furthermore, it has been shown that tunnel displays decrease the monitoring of events that are rendered outside those displays (Olmos, Wickens, & Chudy, 2000; Wickens, Thomas, & Young, 2000). Given these considerations, one of the aims of the present study is to assess whether the compellingness of tunnel displays renders the task they support more resistant to interruptions.

The most familiar property of the IT that is known to produce interruptions is its salience (e.g., Yantis, 1993). In the current research we operationally defined the salience of the IT by the modality of the interrupting cue. Across modalities, there is indeed good evidence that an IT supported by sound will be more likely to capture attention than will one supported by vision (Banbury, Macken, Tremblay, & Jones, 2001; Ho, Nikolic, Waters, & Sarter, 2004; Spence & Driver, 1996, 1997; Woods, 1995). The auditory over visual advantage in the aviation field has been investigated in detail by Latorella (1998). However, her study focused on the effect of interrupting and interrupted task modality on task performance. As far as we know, research has not examined the interaction between the salience of the event cuing the interrupting task and the attention-capturing properties of the display supporting ongoing task performance.

In addition to OT display compellingness and IT salience, a third factor influencing interruptions to be examined in the current research is task importance. The long history of dual-task research has clearly revealed that task importance modulates the allocation of resources between primary and secondary tasks (e.g., Navon & Gopher, 1979) as well as the distribution of visual attention between more or less important tasks (Wickens, Goh, Helleberg, Horrey, & Talleur, 2003), so it is intuitive that this factor should also modulate the interruption pattern between the OT and the IT (Ho et al., 2004). In aviation, task importance has an inherent ranking in terms of the "aviate-navigate-communicate-systems management" or ANCS task hierarchy (Schutte & Trujillo, 1996). However it is also the case that breakdowns in task management often reveal marked departures from this hierarchy, whereby tasks lower in the hierarchy inappropriately preempt more important ones (Chou et al., 1996). In particular, Damos (1997), and Dismukes et al. (2001) have reported the frequency with which auditory-based communication tasks may "preempt" the higher priority navigation tasks, suggesting that bottom-up display features may sometimes override top-down task features (task importance).

With these issues in mind, in the current research we examined the interplay between these three properties of the OT and the IT found elsewhere to influence switching behavior: compellingness of the display supporting the OT, IT salience, and IT importance. Our interest was in assessing the extent to which each variable would exert its influence in isolation, in a realistic flight simulation, and how the combined influence of the three factors might be revealed. In particular, we were interested in determining whether a reciprocity might be observed, such that, for example, a factor inducing greater benefit for an IT would reveal greater cost for the OT. Indeed, in an air traffic control (ATC) task simulation, Ho et al. (2004) found that such reciprocity was not invariably observed.

To investigate this issue, we required pilots to fly three simulated landing approaches. On the final approach, a weather event – a navigational IT – was presented during the flight path tracking task (the OT). The weather event, always visible on the navigational display, could under some circumstances be announced auditorily (via ATC) and was varied to be either more or less important for the safety of the flight. Flight path tracking (the OT) was supported either by a tunnel display or a separated display suite (herein, the baseline display).

METHOD

Participants

Forty instrument-certified pilots (38 men, 2 women; age, *M* = 22.1 years, *SD* = 5.9; experience, *M* = 430 hr) from the Institute of Aviation of the University of Illinois took part in the experiment and were paid $8/hr for their participation.

Equipment

The experiment was carried out in a high-fidelity Frasca twin-seat flight simulator (Frasca Model 142) configured as an Archer Piper III single-engine aircraft, with a forward field of view of 180°. The simulator was equipped with an SVS display with a geometrical field of view of 60° (Figure 1). The SVS display overlaid a computer-generated map of terrain that mimicked the actual view of the terrain that could be seen when looking forward. Standard flight dynamics were coupled with turbulence in the vertical axis to impose a modest level of workload and to force some level of engagement with the primary flight task (aviate). Ownship was represented

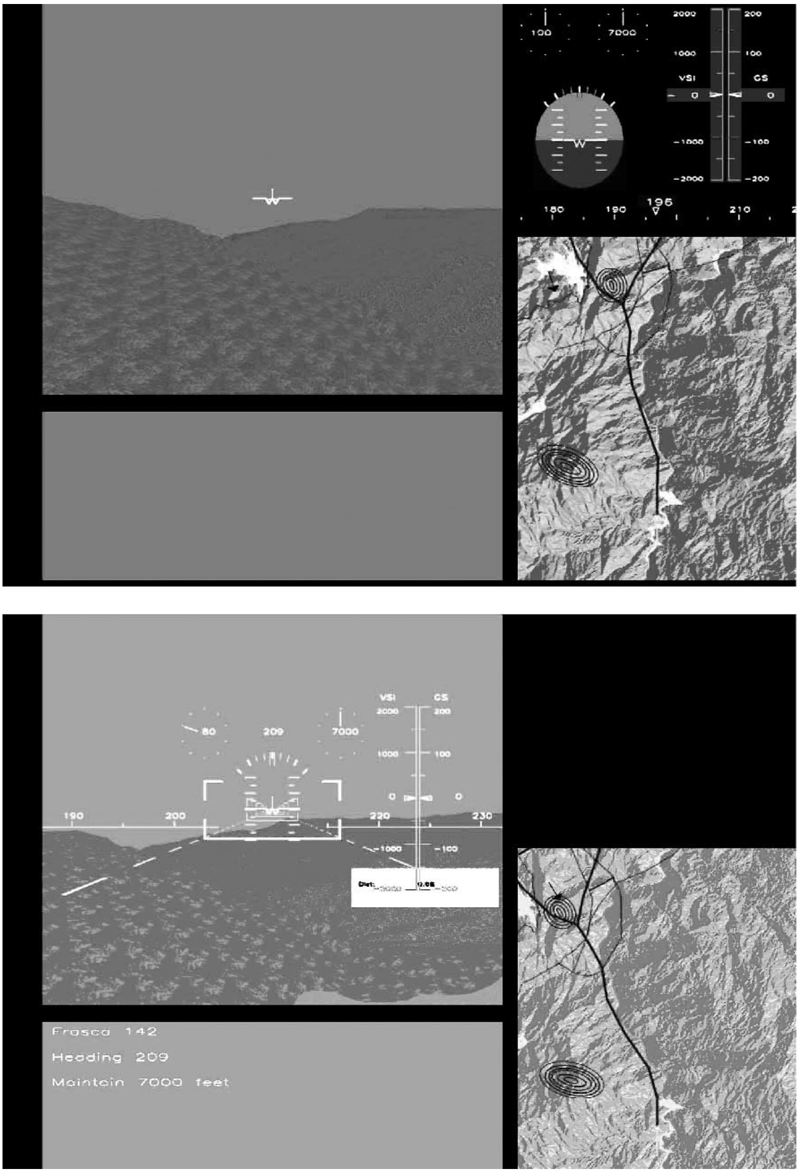


Figure 1. The baseline (top) and tunnel (bottom) synthetic vision system (SVS) displays used in the study.

as a green “W.” A white predictor measuring about 0.4 × 0.4 inches (1 × 1 cm) represented the pilots’ estimated position 5 s ahead of ownship. A two-dimensional electronic map, representing the navigation/hazard display, was placed in the lower right corner of the SVS display (see Figure 2). It depicted terrain, flight course, airplane position, and weather hazards. Flight course was represented in green, and airplane position along the path was represented by a bright pink arrow. Weather information was presented in the form of moving color-coded concentric ellipses. The ellipses could range in color from green, indicating areas with least severe weather, to red, indicating areas with most severe weather.

The instrument panel included speed, altitude, and heading indicators and a vertical situation display. A data link display, providing flight path commands, was positioned just below the terrain representation.

Under the tunnel condition (Figure 1, bottom), the instrument panel and a tunnel providing flight path guidance were overlaid on the terrain display. The tunnel was represented by a series of connected green boxes 300 feet (~91 m) apart. A sliding white box followed the path 5 s ahead of ownship. Pilots maintained their position in the center of the path by keeping the predictor in the center of the white box. Under the baseline condition (Figure 1, top), guidance information supporting the ongoing task was distributed and provided by heading and altitude commands displayed on the data link panel in alphanumeric form. The data link instructions offered the identical guidance information offered by the tunnel.

Design and Procedure

A 2 (display layout: tunnel vs. baseline display) × 2 (interrupting task cue: visual vs. auditory-visual) × 2 (interrupting task importance: high vs. low) between-subjects design was used. Five pilots participated in each condition.

The experiment took approximately 1 hr to complete. Participants were required to manually fly three 8-min curved approaches to land at a synthesized airport over rugged terrain using a digital depicted environment, under instrument meteorological conditions. The first two scenarios, identical in difficulty to the third (in which the IT was presented), were used as practice, and their data were not analyzed.

In all experimental conditions, pilots were identically instructed to assume they were pilots flying a commercial aircraft for a company with a considerable need to maximize profit (e.g., minimize fuel consumption and maintain on-time arrivals to the destination airport) while, at the same time, balancing safety concerns regarding traffic and weather. These instructions were given to induce the pilots to fly the shortest path.

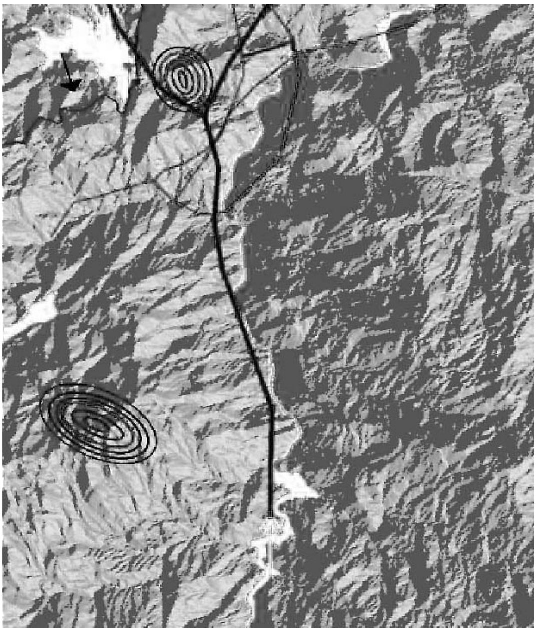


Figure 2. Enlarged navigational display (positioned in the lower right corner of each SVS display) depicting the curving flight paths used during the last scenario. Note the weather symbol moving toward the decision point where the two paths diverge. The black arrow in the upper left corner points north.

After the experiment was completed, pilots were asked retrospectively if they had noticed any change to the weather pattern.

Experimental Task

Each scenario started at the beginning of one of the approach paths to the small airport. During the last scenario, one of the weather systems visible on the navigational display unexpectedly changed direction. This change took place 4 min into the flight and about 45 s before pilots were required to choose which of two branching paths to take for the final approach. This change influenced the ideal path to be chosen and, if noticed, required the pilots to decide whether to take a shorter approach path to the runway (which was depicted on their navigation display as a straight continuation of their current path), at the risk of flying into bad weather, or to take a longer and more circuitous detour path in order to avoid bad weather. The decision required pilots to divert some attention from the "aviate" task of flying the plane with yoke and throttle (the OT) to the navigational choice (the IT).

The actual movement of the weather across the display was sufficiently slow that, in conjunction with the rotation of the navigation display upon which weather was situated, the directional change event itself was imperceptible at the moment that it occurred. In the auditory-visual condition, the need to pay attention to the interrupting task was signaled also by an ATC call informing the pilot about the presence of a thunderstorm on the shorter approach path.

IT importance (high vs. low) was manipulated by changing the severity of the weather. Under the low-importance condition, the change in weather direction would appear to have little effect on the safety of the shorter path. In fact, the weather system was moderate in severity, and even though it was moving toward the shorter approach path following the change, it would not cross the airplane's path. In contrast, under the high-importance condition, the weather was of high severity, and the change in weather direction was designed to clearly decrease the safety of the shorter path. Under the low-importance condition, ATC stated, "Frasca 142. Weather advisory. Thunderstorm in the area." Under the high-importance condition, ATC stated, "Frasca 142. Weather advisory. Thunderstorm on the approach path. Make alternate eastbound approach."

RESULTS

Because of the relatively low sample size for each experimental condition ($n = 5$), data were examined only for main effects and two-way interactions. Deviations in the data larger than three standard deviations from the means were considered as outliers and removed (less than 5% of the data). Because of technical problems with data recording for 1 pilot, all analyses of tracking performance were performed on the data of 39 participants.

Weather Change Detection and Path Choice: The IT

The percentage of pilots who retrospectively reported noticing the change in the trajectory of one of the weather systems was analyzed using the chi-square test. We did not consider those cases in which the pilots reported noticing the weather only after receiving the ATC call.

Detection rates were significantly higher for the participants flying with the tunnel display, $\chi^2 = 6.67$, $p < .01$ (60% vs. 20% for the tunnel and baseline displays, respectively). Also, pilots more frequently reported a weather change when it was cued by the auditory-visual cue (tunnel display: 40% vs. 80% for visual and auditory-visual cues, respectively, $\chi^2 = 3.33$, $p < .07$; baseline display: 0% vs. 40% for visual and auditory-visual cues, respectively, $\chi^2 = 5.00$, $p < .02$). There was no main effect of interrupting task importance (tunnel display: $\chi^2 = 0.22$, $p < .6$; baseline display: $\chi^2 = 0.27$, $p < .6$).

Participants tended to stay on the shorter, more risk-prone (because of the weather) path when the need to divert attention was signaled only by a visual cue, $\chi^2 = 3.75$, $p < .05$ (75% vs. 45% for visual and auditory-visual cues, respectively), irrespective of display layout, $\chi^2 = 2.27$, $p < .32$ (tunnel display: 70% vs. 40% for visual and auditory-visual cues, respectively; baseline display: 80% vs. 50% for visual and auditory-visual cues, respectively). Task importance was significant only when the weather change was signaled by an auditory-visual cue, $\chi^2 = 5.05$, $p < .02$. Under this condition, 8 out of 10 pilots changed path, whereas only 4 out of 10 changed path when the weather change was signaled solely by a visual cue, $\chi^2 = 2.40$, $p < .12$.

Flight Performance: The OT

A one-way ANOVA was performed on mean absolute flight path deviation data with display layout (tunnel vs. baseline) as the between-subjects factor. Because the data were not normally distributed, we used the Kruskal-Wallis test. Consistent with the results of previous studies (Wickens, Alexander, Horrey, Nunes, & Hardy, 2004), the tunnel display ($M = 14.8$ m, $SD = 21.9$) supported better flight performance, $H = 28.98$, $p < .0001$, compared with the baseline display ($M = 202.6$ m, $SD = 137.7$).

Interruption of the Ongoing Task: Flight Performance at the Time of Change

To assess the extent to which IT salience could differentially interfere with primary task (OT) performance, we compared mean absolute flight path deviation before and after the change in weather direction, under the assumption that a more disruptive interruption would, to a greater extent, lead to increased deviations. We computed tracking performance in the 10 s following the change in weather as percentage change from tracking performance in the 5 s preceding the change (baseline performance). Because data for the two SVS display conditions were differentially skewed, we performed different transformations on the data: A log transformation (natural logarithm) was performed on the data for the tunnel display, whereas a square root transformation was performed on the data for the baseline display. For each display layout, the data were then entered into a separate ANOVA for repeated measures with IT cue (visual vs. auditory-visual) and IT importance (high vs. low) as between-subjects factors and time (10 s following weather change) as a within-subject factor. The Huynh-Feldt correction was used when the sphericity assumption was violated.

Surprisingly, for both display layouts, IT cue had no effect on tracking performance. Instead, as shown in Figure 3, a significant interaction between task importance and time was evident for the tunnel display, $F(9, 144) = 2.52$, $p < .04$. Post hoc comparisons showed that tracking error after the change significantly increased only when interrupting task importance was high. No main effect and no interactions were evident for the baseline display.

In order to better assess the effect of task importance on tracking performance, we ran a linear regression on each participant's data to obtain a coefficient representing the slope of the functions depicted in Figure 3, representing the degree of disruption of the OT. These coefficients were then entered into a one-way ANOVA (Kruskal-Wallis test), run separately for each display layout, with task importance as a between-subjects factor.

For the tunnel display, the main effect of IT importance was significant, $H = 4.16$, $p < .04$, with a steep positive slope under the high-importance condition (beta = 19.65) and a slightly negative slope under the low-importance condition (beta = –2.28). The difference between high- and low-importance conditions was only marginally significant for the baseline display, $H = 3.23$, $p < .07$ (beta = 5.22 vs. –0.23 for the high- and low-importance conditions, respectively).

DISCUSSION AND CONCLUSIONS

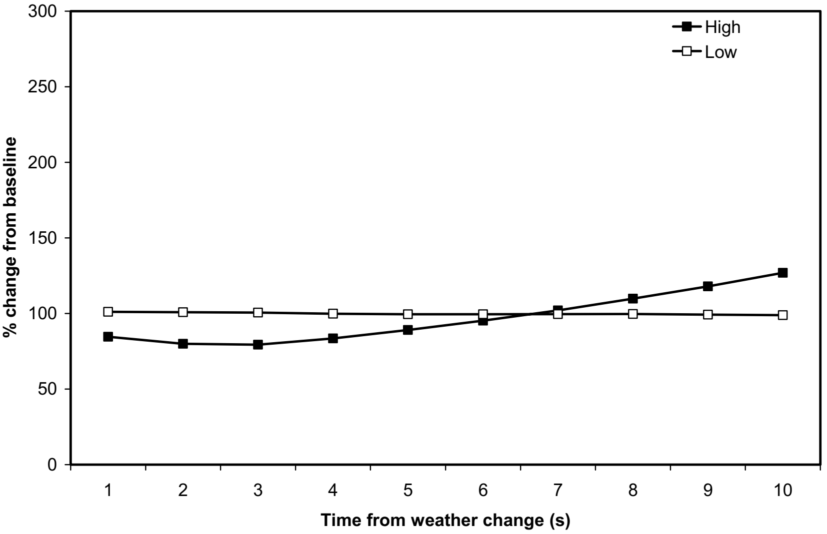
The main objective of the present study was to empirically test the influence of ongoing task display compellingness, interrupting task salience (presence or absence of an auditory cue), and interrupting task importance on attention allocation patterns.

Table 1 presents a relatively simple model of attention switching, which distinguishes between properties of, and influences on, both the ongoing task (here flight path tracking) and the interrupting task (here the navigational choice). According to this simplified model, factors that increase the intrusiveness of the IT will improve its performance, at the expense of the OT, and a converse, reciprocal relationship should be expected. On the left side of each column (representing the OT and IT) the expected predictions of this simplified model are presented in terms of performance improvement (+) or disruption (–).

According to the model, a compelling OT display should protect the OT, preventing or delaying the switch to the IT. Conversely, an IT that is of great importance and/or announced by an auditory salient cue should disrupt the OT. On the right side of each column, we show the extent to which these simplified predictions of a "reciprocity" of effects between the IT and OT were confirmed in the present study.

First, increasing IT salience, through auditory-visual cuing, was predicted to produce greater OT disruption. However, we found that auditory-visual cue presentation captured attention, as indicated by the higher rates of weather change report and safer flight path choices, but did not produce greater disruption of the flight path tracking (the OT), thereby replicating the findings of Ho et al. (2004). Second, increasing IT importance was predicted to increase compliance with the IT. Our data showed that when IT salience was low, IT importance had no effect on either weather detection or path choice. However, the IT disrupted OT performance, particularly when the latter was supported by the tunnel display.

Most prominent in the current data is the direct contradiction with the concerns that the tunnel



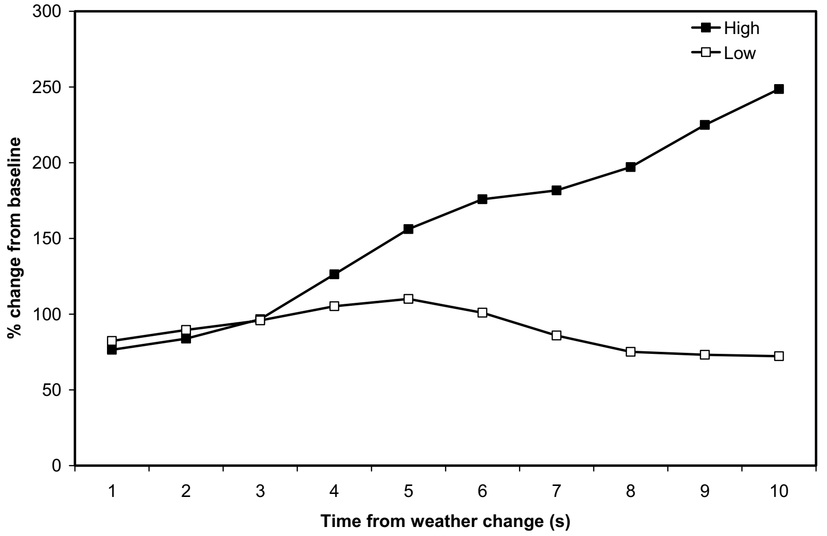


Figure 3. Second-by-second tracking deviation in the 10 s following weather change for the baseline (top) and tunnel (bottom) displays. Tracking deviation is expressed as percentage change from baseline tracking performance in the 5 s preceding the weather change.

display produces attentional tunneling (bottom row of Table 1). Had such a display produced attentional tunneling, it would have better sustained performance on the OT and led to greater delay of (or less compliance in) responding to the IT cue. However, the opposite pattern was observed. For instance, pilots flying with the tunnel were more likely to detect the change in weather and were more easily interrupted when the change in weather represented an important threat to the safety of the flight. In interpreting these latter effects, we should consider that the tunnel display can have two counteracting influences on performance, only one of which was considered in our switching model. On the one hand, under some circumstances (not examined here), it appears that the very compellingness of the tunnel may prevent pilots from noticing very unusual events (see Wickens, 2005, for a review). On the other hand, the tunnel's greater ease of processing, which is well documented here and in prior studies (e.g., Wickens et al., 2004), avails more resources, rather than fewer, to monitor other important areas and to deal with newly

TABLE 1: Simplified Model Summarizing the Interactions (Predicted and Found) Between Properties of, and Influences on, the Ongoing Task (OT) and the Interrupting Task (IT)

	OT		IT	
	Predicted	Found	Predicted	Found
Increasing IT cue salience	–	0	+	+
Increasing IT importance	–	–	+	0
Compelling display for OT	+	–[a]	–	+

Note. A plus sign indicates performance improvement, a minus sign indicates performance disruption, and a zero indicates no effect.

[a] When IT importance is high.

arriving information, hence leading to better processing of that information (fewer high-risk choices) and to a more rapid disengagement from the flight control task (as witnessed by the increase in flight path error shown in Figure 3).

Two factors could explain why in the present study the benefits of reduced workload might have dominated the attentional tunneling costs observed in other studies. First, in the current paradigm, monitoring for the IT event – a weather change – although somewhat unexpected (it had not happened during the first two flights), was still a part of the pilots' responsibilities. In contrast, in other studies (e.g. Wickens, 2005), the unnoticed event was a truly surprising system failure for which little prior expectations existed. Second, in the current study, IT delivery occurred within the cockpit, whereas in prior studies demonstrating immersion-driven tunneling (operationally defined by reduced detection), the IT event was visible only in the outside world.

Also, two aspects of the modality results deserve particular mention. First, consider the relatively low rate of weather change detection. In the visual condition, this low value is understandable because the changes were subtle and the pilots were not accustomed to flying with dynamic weather displays. However, it should be noted that when delivery was auditory-visual and important, 8 out of 10 pilots did comply with the ATC instructions. We may simply assume that those pilots who did not comply with the implicit guidance simply treated the ATC instruction as advisory.

Second, it should be noted that the difference between the auditory-visual and visual-only conditions was confounded with redundancy: In the visual condition information was presented in a single modality, whereas in the auditory-visual condition two modalities were concurrently used to convey the same information. However, given the extremely low salience of the visual change, we doubt that pilot response in the auditory-visual condition would have varied if the visual display were absent. More important, in terms of a confound with modality, it should be noted that the auditory delivery was verbal (speech), whereas our visual delivery was spatial (a slow dynamic change). It is quite possible that a different pattern of results could have emerged had we employed a more salient text version for the visual delivery.

In conclusion, the results reported here support the view that the auditory modality has important attention-capturing features, but they also seem to suggest that this capture does not necessarily disrupt high-priority ongoing tasks (e.g. aviating), given the ability of the auditory modality to support parallel processing of visual flight control information (Wickens, Alexander, & Hardy, 2003). The general absence of reciprocity of effects between the OT and the IT replicates the pattern of results by Ho et al. (2004) and suggests that these effects may not act as "two sides of the same coin."

In terms of practical implications, the current results provide another positive data point supporting the utility of the tunnel display. Its advantages for conventional flight path tracking have been known for a long time. However, the current data also suggest that some of the concerns regarding the negative consequences of its compelling nature may not be as pronounced as once thought. Because the time to detect changes in the environment signaling the need to switch to a secondary task seems to be sensitive to the type of tasks involved (e.g., Goodrich, Quigley, & Cosenzo, 2005), future studies should investigate the effect of task compellingness with interrupting tasks of a different nature.

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REFERENCES

Banbury, S. P., Macken, W. J., Tremblay, S., & Jones, D. M. (2001). Auditory distraction and short-term memory: Phenomena and practical implications. *Human Factors, 43,* 12–29.

Chou, C. D., Madhavan, D., & Funk, K. (1996). *Studies of cockpit task management errors. International Journal of Aviation Psychology, 6,* 307–320.

Damos, D. (1997). Using interruptions to identify task prioritization in Part 121 air carrier operations. In R. S. Jensen (Ed.), *Proceedings of the 9th International Symposium on Aviation Psychology* (pp. 871–876). Columbus, OH: Department of Aerospace Engineering, Ohio State University.

Dismukes, R. K., Loukopoulos, L. D., & Jobe, K. K. (2001). The challenges of managing concurrent and deferred tasks. In R. S. Jensen (Ed.), *Proceedings of the 11th International Symposium on Aviation Psychology* (CD-ROM). Columbus, OH: Department of Aerospace Engineering, Ohio State University.

Funk, K. H. (1991). Cockpit task management: Preliminary definitions, normative theory, error taxonomy, and design recommendations. *International Journal of Aviation Psychology, 1,* 271–285.

Goodrich, M. A., Quigley, M., & Cosenzo, K. (2005). Task switching and multi-robot teams. Paper presented at the *Third International Multi-Robot Systems Workshop*, March 14–16, Washington, DC.

Ho, C.-Y., Nikolic, M. I., Waters, M. J., & Sarter, N. B. (2004). Not now! Supporting interruption management by indicating the modality and urgency of pending tasks. *Human Factors, 46,* 399–409.

Latorella, K. A. (1998). Effects of modality on interrupted flight deck performance: Implications for data link. In *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting* (pp. 87–91). Santa Monica, CA: Human Factors and Ergonomics Society.

Liao, J., & Moray, N. (1993). A simulation study of human performance deterioration and mental workload. *Le Travail Humain, 56,* 321–344.

McFarlane, D. C., & Latorella K. A. (2002). The scope and importance of human interruption in human-computer interaction design. *Human-Computer Interaction, 17,* 1–61.

Monsell, S. (2003). Task switching. *Trends in Cognitive Neuroscience, 7,* 134–140.

Navon, D., & Gopher, D. (1979). On the economy of the human processing system. *Psychological Review, 86,* 214–255.

Olmos, O., Wickens, C. D., & Chudy, A. (2000). Tactical displays for combat awareness: An examination of dimensionality and frame of reference concepts and the application of cognitive engineering. *International Journal of Aviation Psychology, 10,* 247–271.

Prinzel, L., Comstock, R., Glaab, L., Kramer, L., Jarvis, J., & Barry, J. (2004). The efficacy of head down and head up synthetic vision display concepts for retro- and forward-fit of commercial aircraft. *International Journal of Aviation Psychology, 14,* 53–78.

Raby, M., & Wickens, C.D. (1994). Strategic workload management and decision biases in aviation. *International Journal of Aviation Psychology, 4,* 211–240.

Rubinstein, J. S., Meyer, D. E., & Evans, J. E. (2001). Executive control of cognitive processes in task switching. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 763–797.

Schutte, P. C., & Trujillo, A. C. (1996). Flight crew task management in nonnormal situations. In *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting* (pp. 244–248). Santa Monica, CA: Human Factors and Ergonomics Society.

Society of Automotive Engineers. (2005). *Aerospace recommended practice ARP 5589: Human engineering considerations for perspective flight guidance displays.* Warrendale, PA: Author.

Spence, C., & Driver, J. (1996). Audiovisual links in endogenous covert spatial orienting. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 1005–1030.

Spence, C., & Driver, J. (1997). Audiovisual links in exogenous covert spatial orienting. *Perception and Psychophysics, 59,* 1–22.

Thomas, L. C., & Wickens, C. D. (2004). Eye-tracking and individual differences in off-normal event detection when flying with a synthetic vision system display. In *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting* (pp. 223–227). Santa Monica, CA: Human Factors and Ergonomics Society.

Wickens, C. D. (2005). *Attentional tunneling and task management* (Tech. Rep. AHFD-05-23/NASA). Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.

Wickens, C. D., Alexander, A. L., & Hardy, T. J. (2003). *The primary flight display and its pathway guidance: Workload, performance, and situation awareness* (Tech. Rep. AHFD-03-02/NASA). Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.

Wickens, C. D., Alexander, A. L., Horrey, W. J., Nunes, A., & Hardy, T. J. (2004). Traffic and flight guidance depiction on a synthetic vision system display: The effect of clutter on performance and visual attention allocation. In *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting* (pp. 218–222). Santa Monica, CA: Human Factors and Ergonomics Society.

Wickens, C. D., Goh, J., Helleberg, J., Horrey, W. J., & Talleur, D. A. (2003). Attentional models of multitask pilot performance using advanced display technology. *Human Factors, 45,* 360–380.

Wickens, C. D., Thomas, L. C., & Young, R. B. (2000). Frames of reference for the display of battlefield information: Judgment-display dependencies. *Human Factors, 42,* 660–675.

Woods, D. D. (1995). The alarm problem and directed attention in dynamic fault management. *Ergonomics, 38,* 2371–2394.

Yantis, S. (1993). Stimulus-driven attentional capture. *Current Directions in Psychological Science, 2,* 156–161.

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