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Factors Affecting Task Management in Aviation

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Running head: Task management in aviation

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Abstract

Objective: We investigated task management and task prioritization processes in aviation.

Background: The airplane cockpit represents a multi-task environment where issues of good and poor task management have important safety implications. Because of the potential severe consequences of task prioritization errors, research effort should be aimed at discovering which factors can influence this process.

Methods: Forty instrument rated 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 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 and applications: In terms of practical implications, the current results support the utility of the tunnel display and suggest that some of the concerns, regarding the negative consequences of its compelling nature, may not be as pronounced as once thought.

INTRODUCTION

Issues of task management have gained considerable prominence in research in many complex multi-task 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., Rubinstein, Meyer, & Evans, 2001; Monsell, 2003). In many respects the airplane cockpit is the prototypical multi-task environment where issues of good and poor task management have important safety implications (Funk, 1991; Chou, Madhavan, & Funk, 1996; Dismukes, Loukopoulos, & Jobe, 2001). For example, Chou et al. (1996) identified that 23% of aircraft accidents occurred during a ten-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. While such a label invites a danger of circularity (tasks are called compelling if they resist interruptions, and compelling tasks 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 the flight deck tunnel displays, which are characteristic of the so called Synthetic Vision Systems (SVS; 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 (SAE, 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 (Wickens, 2005; Thomas & Wickens, 2004). 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 the 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 one supported by vision (Wood, 1995; Spence & Driver, 1996, 1997; Banbury, Macken, Tremblay, & Jones, 2001; Ho, Nikolic Waters, & Sarter, 2004). The auditory over visual advantage in the aviation field has been investigated in details 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 cueing 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 so called “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, the goal of the current research was to examine 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 ATC task simulation, Ho et al. (2004) found that such reciprocity was not invariably observed.

To investigate this issue, pilots were required 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 auditorally (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, baseline display).

METHOD

Participants

Forty instrument certified pilots (38 males, 2 females; age, $M=22.1$ years, $SD=5.9$; experience, $M=430$ hours) 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 degrees. The simulator was equipped with a Synthetic Vision System (SVS) display with a geometrical field of view of 60 degrees (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 as a green “W”. A white predictor measuring 20 x 60 x 20 ft represented the pilots’ estimated position five seconds ahead of ownship. A 2D electronic map, representing the Navigation/Hazard Display, was placed in the lower right corner of the SVS display. 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.

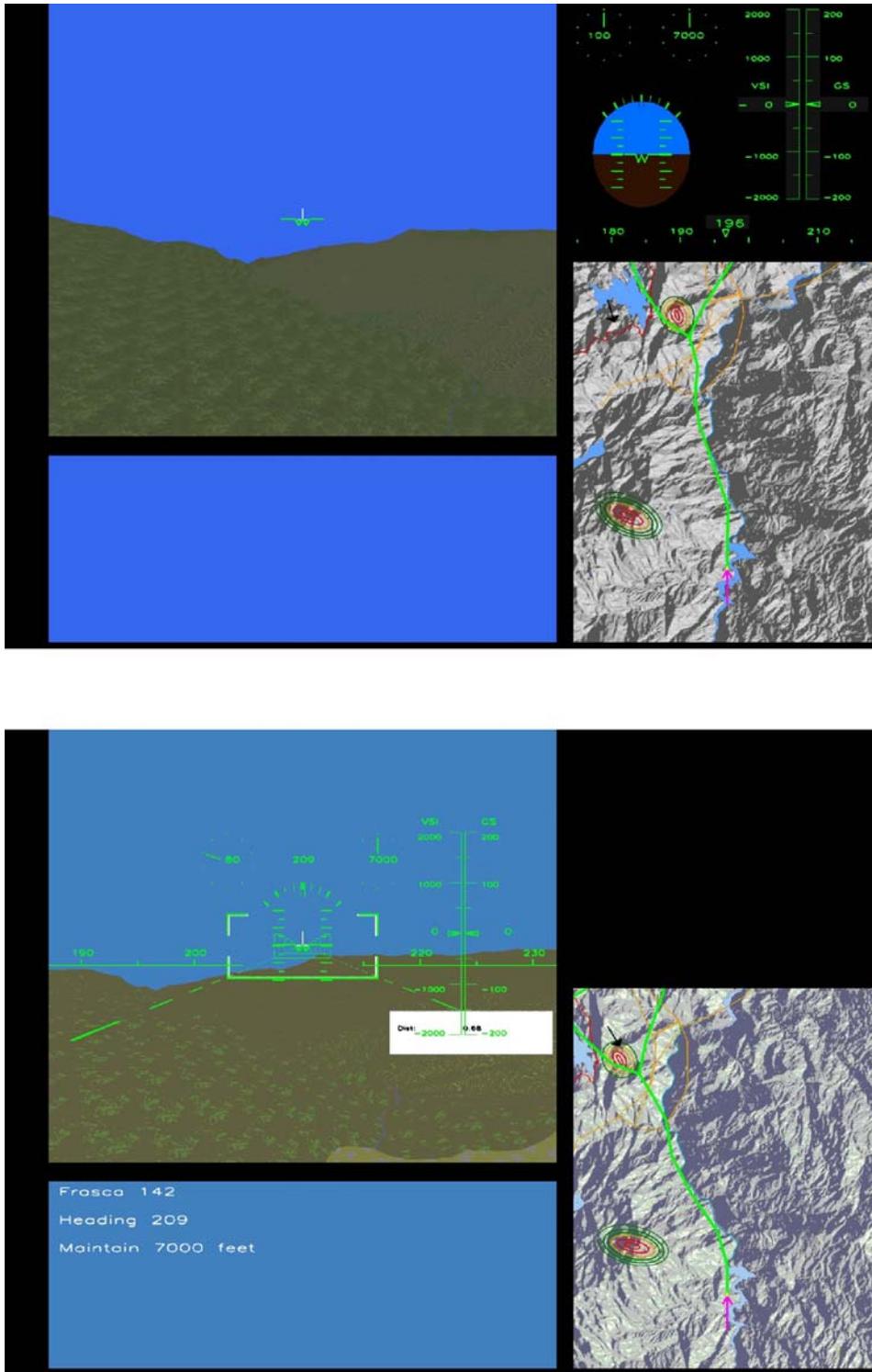


Figure 1. The baseline (top) and tunnel (bottom) Synthetic Vision System (SVS) displays used in the study. The navigational display in the bottom right of each panel depicts the curving flight paths used during the last scenario. Note the weather symbol moving toward the decision point where the two paths diverge. The black arrow indicates where the North is.

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, 300ft apart. A sliding white box followed the path five seconds 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 verbal/numeric 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) X 2 (interrupting task cue: visual, V vs. auditory-visual, AV) X 2 (interrupting task importance: high vs. low) between-subjects design was used. Five pilots participated in each condition.

The experiment took approximately one hour 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 (IMC). The first two scenarios, identical in difficulty to the third, where the IT was presented, were used as practice and 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.

After the experiment was completed, pilots were asked retrospectively if they 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 four minutes into the flight, and about 45 seconds 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), risking to fly 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 track up 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 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 only examined for main effects and two-way interactions. Deviations in the data larger than 3 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 one pilot, all analyses of tracking performance were performed on the data of thirty-nine 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 V and AV cues, respectively; $\chi^2=3.33$, $p<.07$; baseline display: 0% vs. 40% for V and AV 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 V and AV cues, respectively), irrespective of display layout, $\chi^2=2.27$, $p<.32$ (tunnel display: 70% vs. 40% for V and AV cues, respectively; baseline display: 80% vs. 50% for V and AV 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, while 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 analysis of variance (ANOVA) was performed on mean absolute flight path deviation data with display format (tunnel vs. baseline) as 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 to 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 seconds following the change in weather as percentage change from tracking performance in the five seconds preceding the change (baseline performance). Since 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, while 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 seconds following weather change) as within-subject factor. The Huynh-Feldt correction was used when the sphericity assumption was violated.

Surprisingly, for both display formats, IT cue had no effect on tracking performance. Instead, as shown in Figure 2, 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.

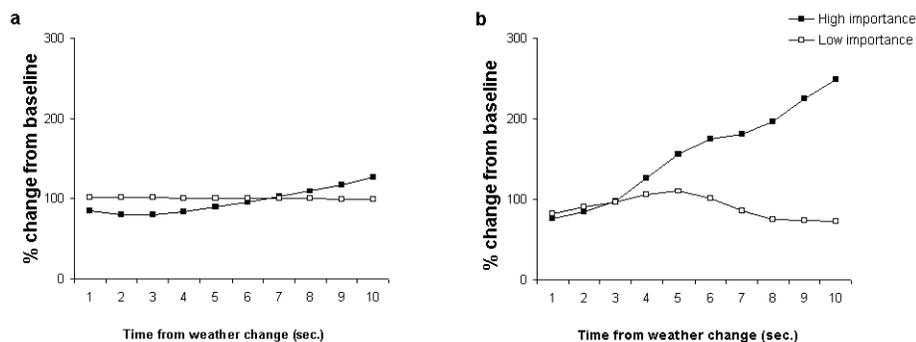


Figure 2. Second-by-second tracking deviation in the ten seconds following weather change for the (a) baseline and (b) tunnel displays. Tracking deviation is expressed as percent change from baseline tracking performance in the five seconds preceding the weather change.

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 2, 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 format, with task importance as 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. $\beta=-0.23$ 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 (-).

Table 1

A simplified model summarizing the interactions (predicted and found) between properties of, and influences on, the ongoing task (OT) and the interrupting task (IT). A plus sign indicates performance improvement, a minus sign indicates performance disruption, and a zero indicates no effect.

	OT		IT	
	Predicted	Found	Predicted	Found
Increasing IT cue salience	-	0	+	+
Increasing IT importance	-	-	+	0
Compelling display for OT	+	- *	-	+

* When IT importance is high

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 cueing, 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 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, while leading 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 noticing very unusual events (see Wickens, 2005 for a review). On the other hand, the tunnel’s greater ease of processing, 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 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 2).

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 – while 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 only visible in the outside world.

Also, two aspects of the modality results deserve particular mention. First, we 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: while in the visual condition, information was presented in a single modality, 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 (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 seem also 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. Since 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 different nature.

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