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FACTORS AFFECTING TASK MANAGEMENT IN AVIATION

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The present paper summarizes the results of a study investigating task management and task prioritization processes in aviation. 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 level of immersion in the task, the nature and saliency of the cues signaling the need to divert attention to the path selection task and the cost of not performing the secondary task were manipulated to investigate their influence on task prioritization. Our results indicate that cue saliency affected the frequency of the switch to the secondary task, while task compellingness did not show any reliable effect on task prioritization.

INTRODUCTION

During flights, pilots are frequently required to perform several tasks concurrently (e.g., searching for traffic or communicating to ATC while controlling the aircraft). While some tasks can be easily performed in parallel, others compete for resources (Wickens, 1984; 2002) and pilots need to decide how, when, and with what priorities they will be performed.

Under controlled laboratory conditions, performers seem to be very efficient in allocating attention according to the implicit or explicit priority given to a task (Gopher & North, 1977; Navon & Gopher, 1979). However, in real world settings, task prioritization is not always efficient. For instance, despite the fact that pilots are taught during training to follow the "aviate, navigate, communicate and system manage" hierarchy in deciding which task to attend to at any given moment (Schutte & Trujillo, 1996), there is ample evidence that this hierarchy is vulnerable to violations (Dismukes, Young and Sumwalt, 1998; Funk, 1991; Strauch, 1997). Common violations include attending to one task when attention should instead be devoted to another task or failing to perform a task at a proper time.

Because of the potential severe consequences of task prioritization errors, several studies have tried to discover which factors can influence this process (Colvin, 2000; Freed, 2000). However, the specific manner in which environmental and task properties interact and influence the decision of what task to perform and when remains poorly understood.

The purpose of this study was to investigate the role of three factors that, from the analysis of the available literature, seem to play a predominant role in influencing task prioritization.

The first factor is the degree of engagement in an ongoing task. If the ongoing task is compelling the human may be less likely to switch to other tasks, and the switch may be slower (Logan, 2003). In other words, the compellingness of the task at hand may decrease the awareness that other tasks need to be performed.

The second factor is the saliency of the cue signaling the need to allocate attention to a secondary task. The results of several studies suggest that salient sensory annunciators or reminders are more likely to trigger a switch to a task than less salient properties, or purely memorial

representations (Wickens and Seidler, 1997). Furthermore, tasks with salient stimuli tend to distract subjects from even higher priority flight control tasks (Chou et al., 1996).

The third factor is task importance. The importance of a task, relative to other competing tasks, seems to determine were the performers will focus his/her attention (Colvin, 2000; Wickens et al., 2003).

In the present experiment, participants were required to fly curved approaches over rugged terrain, through potentially hazard weather, in a flight simulator. In order to manipulate task compellingness, we used two Synthetic Vision Systems (SVS) display formats, depicting 3D terrain either with or without tunnel guidance. Previous studies indicated that the tunnel of the SVS supports better flight performance, but represents a particularly "compelling" display, from which attention may be less easily switched (Wickens et al., 2003). During the last approach, pilots were required to select a flight path on the basis of weather information available on the display. We varied saliency by the modality of information relevant for a flight path decision, assuming auditory presentation to be more salient than visual (e.g., Latorella, 1997). The need to allocate attention to the path selection task could therefore be signaled either by a visual cue (less salient) or by the combination of visual and auditory cues (more salient).

In agreement with the literature presented, we predicted that if the compellingness of the task influences task prioritization, the switch of attention to the secondary task should be neglected or delayed when pilots are presented with the immersive display. We expected this behavior to be modulated by the nature of the event signaling the need to switch to the secondary task. More precisely, the secondary task should be neglected or delayed only when the cue signaling the need to allocate attention to the secondary task is visual.

METHODS

Participants

Forty instrument certified pilots (Age, $\underline{M}$=22.1 years; Experience, $\underline{M}$=432.4 hours) from the University of Illinois Institute of Aviation participated in the experiment. None of the participants was familiar with the experimental task and the display layouts.

Equipment and Displays

The experiment was carried out in a high-fidelity Frasca flight simulator equipped with a SVS display. The SVS display overlaid a 3D computer generated map of terrain that mimicked the actual view of the terrain that could be seen when looking forward. 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. Weather information was presented in the form of moving color-coded concentric ellipses. 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.

Task and procedure

Participants were asked to fly three 15-min curved approaches under instrument meteorological conditions. They were instructed to pretend they were 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, instructions that induced pilots to fly the shortest path), while at the same time, balancing safety concerns regarding traffic and weather. Each scenario started at the beginning of one of the approach paths to a two–runway airport. During the last scenario they were required to decide whether to take a shorter approach path which was 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 to divert some attention from the "aviate" task (primary task) to the navigational choice (secondary task). To render the task more difficult, perturbation

in the vertical axis was present throughout the scenario.

Design

Task compellingness, cue saliency and secondary task importance were manipulated between subjects in a 2X2X2 design. Under the **compelling condition**, the instrument panel and a tunnel providing flight path guidance were overlaid on the terrain display. Under the **baseline condition**, the tunnel was absent and guidance was provided solely by text commands presented in the data link display.

In the **low saliency** (visual cue only, V) condition, the need to switch attention to the path selection task was signaled by a discrete change in the direction of one of the weather systems visible on the navigational map. This change took place right before pilots had to choose which path to take for the final approach, and influenced the ideal path to be chosen. Before the weather change, the shorter path was as safe as the longer one. After the change, the weather would take a course directly over the shorter path, while leaving the longer path risk free. In the **high saliency** condition (auditory and visual cues, AV), the need to pay attention to the secondary task was signaled by an ATC call, informing about the presence of a thunderstorm on the shorter approach path.

The importance of the secondary task was manipulated by changing the severity of the weather. Under the **high importance** condition, the change in weather direction was designed to decrease the safety of the shorter path. Differently, under the **low importance** condition, the change had no effect on the safety of the shorter path. At the end of the experiment, pilots were asked whether they had noticed the change in the trajectory of the weather.

RESULTS

The following independent variables were analyzed: mean absolute deviation (combined lateral and vertical deviation), mean absolute stick velocity, path choice and correct change detection. To assess the extent to which differences in saliency and compellingness could differentially interfere with primary task performance, we compared mean absolute deviation and mean absolute stick velocity before and after the change in weather direction.

For the purpose of simplicity, only the main effect of task compellingness and cue saliency are analyzed here.

Overall flight performance

An analysis of variance (ANOVA) was performed on deviation data. Because the data were not normally distributed we used the Kruskal-Wallis test.

The immersive display supported better flight performance compared to the baseline display, X^2=28.98, p<.0001 (M=14.8 m, SD=21.9 and M=202.6 m, SD=137.7 for immersive and baseline display, respectively).

Path selection

Table 1 presents the frequency of each path choice. Overall, participants tended to stay on the shorter, more risk-prone path (because of the weather) when the need to divert attention was signaled only by the visual event (change in weather heading), X^2=3.75, p<.05. Choice was not affected by flight path display type.

	V		AV	
	Path		Path	
	Short	Long	Short	Long
Immersive	70	30	40	60
Baseline	80	20	50	50

Table 1: Percentage of each path choice as a function of task compellingness and cue saliency.

Change detection

As shown in Table 2, retrospective weather change detection rates were significantly higher for the participants presented with the immersive display, X^2=6.67, p<.01. None of the participants presented with the baseline display noticed the weather change when no auditory cue was present, X^2=5.00, p<.02. The majority of the participants

reported noticing the weather only after receiving the ATC call, even though, in both AV and V conditions, the change in weather direction had identical safety implications. For the compelling display, weather change detection was higher with the AV, an effect of marginal significance, $X^2=3.33$, $p<.07$.

	V	AV
Immersive	40	80
Baseline	0	40

Table 2: Subjective retrospective reports (in percentage) of noticing weather change as a function of task compellingness and cue saliency.

Flight performance at the time of change

An analysis of variance (ANOVA) was performed on deviation data and stick velocity data to assess whether flight performance in the 10 seconds following the weather change differed from the 10 seconds preceding the change. Although no significant difference was found, visual inspection of the deviation data reveals some interesting trends. As can be seen in Figure 1, for the participants presented with the baseline display, the presentation of an auditory cue was followed by a slight increase in mean absolute deviation. Such a response did not occur when the change was only visual. A different result is evident for the participants presented with the immersive display (figure 2): the change in weather was followed by an increase in mean absolute deviation only when the cue was solely visual.

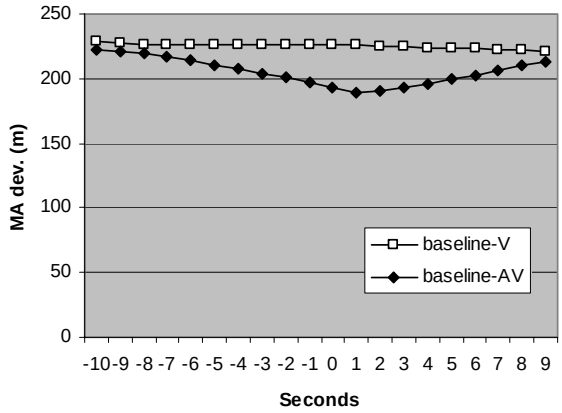

Figure 1: Second-by-second mean absolute deviation before and after the change for the baseline display.

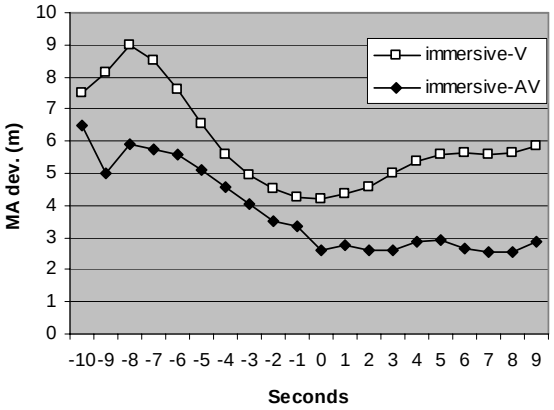

Figure 2: Second-by-second mean absolute deviation before and after the change for the immersive display.

Examination of the control activity data did not reveal any noticeable differences between conditions in the seconds following the introduction of the weather change, whether signaled by an auditory or visual cue.

CONCLUSIONS

We had originally hypothesized that the auditory delivery of weather safety information (compared to visual delivery inherent in the change of the weather display) would be (a) more likely to capture attention and lead to a flight path change, (b) more likely to disrupt the ongoing primary task of maintaining straight and level flight, through an auditory "preemption" effect. In fact, we found only the first of these predictions to be upheld by the data. Auditory presentation did lead to safer flight path choices, but produced less, rather than more disruption of the flight path tracking.

We had also hypothesized that attention switching would be moderated by the "compellingness" of the tunnel, leading pilots in the tunnel group to be less likely to notice the weather changes. Yet the data shown in table 2 reveals precisely the reverse findings. Instead of a disruption from being more compelling, we interpret these findings to reflect the lower

workload of flying with the tunnel. Pilots had more visual resources available to monitor the visual hazard display and notice the weather changes (although this did not lead to a significant advantage in actual safe route choices; table 1).

In conclusion, the results do support the view of the auditory modality as having important attention-capturing features, but may suggest also that this capture does not necessarily disrupt ongoing tasks, given the ability of the auditory modality to support parallel processing of visual flight control (Wickens et al., 2003). The question of whether the advantage of the tunnel in supporting lower effort flight control may be offset by the cost of its more compelling nature, as some have feared, appears from these data to be answered in the negative.

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REFERENCES

Chou, C.D., Madhavan, D., & Funk, K. (1996). Studies of Cockpit Task Management Errors. *The International Journal of Aviation Psychology, 6*(4), 307-320.

Colvin, K.W. (2000). *Factors that affect task prioritization on the flight deck*. Dissertation Abstracts International, 61(2-B). US: University Microfilms International.

Dismukes, R.K., Young, G., & Sumwalt, R. (1998). Cockpit interruptions and distractions: Effective management requires a careful balancing act. *ASRS Directline, 10*, 3.

Freed, M. (2000). Reactive prioritization. In *Proceedings of the 2nd NSA International Workshop on Planning and Scheduling in Space*. San Francisco, CA.

Gopher, D., & North, P. A. (1977). Manipulating the conditions of training in time-sharing performance. *Human Factors, 19*, 583-594.

Funk, K.H. (1991). Cockpit task management: preliminary definitions, normative theory, error taxonomy, and design recommendations. *The International Journal of Aviation Psychology, 1*(4), 271-285.

Latorella, K. (1997). *Investigating interruptions: Implications for flight deck performance.* Unpublished doctoral dissertation, State University of New York at Buffalo.

Logan, G.D. (2003). Executive control of thought and action: In search of the homunculus. *Current Direction in Psychological Science, 22*(2), 45-48.

Navon, D., & Gopher, D. (1979). On the economy of the human processing system. *Psychological Review, 86*(3), 214-255.

Schutte, P.C., & Trujillo, A.C. (1996). Flight Crew Task Management in Non-normal Situations. In *Proceedings of the 40th Annual Meeting of the Human Factors and Ergonomics Society*. Santa Monica, CA: HFES.

Strauch, B. (1997). Automation and decision making: Lessons from the Cali accident. In *Proceedings of the 41st Annual Meeting of the Human Factors and Ergonomics Society*. Santa Monica, CA: HFES.

Wickens, C.D. (1984). Processing resources in attention. In R. Parasuraman & R. Davies (Eds.), *Varieties of attention*. New York: Academy Press.

Wickens, C.D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomic Science, 3*(2), 159-177.

Wickens, C.D., & Liu, Y. (1988). Codes and modalities in multiple resources: A success and a qualification. *Human Factors, 30*, 599-616.

Wickens, C.D., & Seidler, K.S. (1997). Information access in a dual-task context. *Journal of Experimental Psychology: Applied, 3*, 1-20.

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

Wickens, C. D., Goh, J., Helleberg, J, Horrey, W., & Talleur, D. A. (2003). Attentional models of multi-task pilot performance using advanced display technology. *Human Factors, 45*(3), 360-380.