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ASSESSING VISUAL ATTENTION OF PILOTS WHILE USING ELECTRONIC MOVING MAPS FOR TAXIING

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ABSTRACT

This study represents a preliminary behavioral assessment of pilot visual attention while using an Electronic Moving Map (EMM) for taxiing under various levels of visibility and training. The results suggests that implementing EMM displays for low-visibility surface operations should not have a negative impact on allocation of pilot visual attention in either low- or high-visibility conditions. The data also suggests that training is necessary to assure proper usage of, and optimal visual attention interaction with, the EMM.

INTRODUCTION

Ground taxi is an essential element affecting the flow rates at commercial airports, and poor weather poses many challenges to accomplishing this task. In an effort to increase terminal area productivity in low visibility conditions, NASA developed the Taxiway Navigation and Situation Awareness (T-NASA) cockpit suite (see Foyle et al., 1996). One of the main components of T-NASA is an EMM display, developed to increase navigation situation awareness, decrease navigation errors, increase forward taxi speeds, decrease planning time, decrease navigation mental workload, and improve navigation communications of pilots in low-visibility conditions.

Benefits of EMM s

Previous simulation studies pitting EMM s vs. paper maps have shown that EMM s produce significant improvements in 1) performance over paper maps (McCann et al., 1996; McCann et al., 1997; Batson, Harris, and Hunt, 1994), 2) the ability to correct navigation errors without contacting ATC (Irwin and Walter, 1996), 3) the ability to correct navigation errors faster (Irwin and Walter, 1996), 4) higher mean forward taxiing speeds (Batson, Harris, and Hunt, 1994; Battiste et al., 1996; McCann et al., 1996; McCann et al., 1997; Tu and Andre, 1996), 5) improved centerline tracking (Batson, Harris, and Hunt, 1994), 6) increased situation awareness (Batson, et al., 1994; McCann et. al., 1996), and 7) decreased planning times (McCann et. al., 1996; McCann et. al., 1997). A recent field test of the T-NASA system revealed similar benefits under real-world operating conditions (Andre, Hooey, Foyle and McCann, 1998).

Beyond Performance

While much emphasis has been placed on the EMM s potential for increasing airport throughput, little attention has been directed toward assessing the behavioral influence of the display. The data from the aforementioned studies show that EMM s have high potential for positively affecting performance measures, but do these gains come at a cost of inappropriate visual attention allocation and information access behaviors?

Visual Attention Concerns

As with all displays introduced into the aircraft cockpit, there are concerns that the EMM may disproportionately draw the pilot s eyes into the cockpit during taxi. With the exception of scrutinizing the paper map and interacting with the radio controls and other pre-flight check-list items, taxiing is an eyes-out task. Pilots navigate the airport and terminal areas using visual cues and signage from the outside environment, and through communication with ground control. Their task is to accurately navigate the cleared route, monitor for potential incursions, and maintain a safe distance from other aircraft, ground vehicles, and obstacles, --a task best served by keeping their heads-up and eyes-out the cockpit windshield.

Andre (1995) noted that, coupled with the excitement surrounding the EMM, there was concern about adding an eyes-in display to assist an eyes-out task. Several pilots had comments regarding this concern, including the following:

- I don t want a display that keeps me heads-down while taxiing. Even at night and in poor weather I see things out the window (lights on other aircraft, runway markers)
- I like the idea of a moving map display for taxi operations, but it should be a secondary display, not a primary display, since it requires me to be heads down .

Based in part on these concerns, Andre (as discussed in Foyle et al., 1996; Andre et al., 1998) developed the EMM with the goal of supporting eyes-out behavior. To this end, the EMM was designed to afford eye-out navigation rather than eye-in control, and is intentionally devoid of certain display characteristics that might afford the latter activity (e.g., centerlines, turn predictors). Yet, to date, the achievement of this behavioral goal has not been addressed utilizing appropriate visual scanning methodologies and measurement tools.

The Present Study

The main objective of this study was to understand how pilots visually interact with the EMM, and how this interaction is mediated by three different combinations of visibility and time of day: daytime high visibility (Day Visual Meteorological Conditions), daytime low visibility (Day 700 Runway Visual Range), and nighttime moderate visibility (Night 1,400 RVR). As the visibility degraded or time of day progressed, we expected to see an increase in the percent of time pilots visually attended to the EMM, at the expense of visual attention to events out-the-window.

A secondary objective of this study was to determine the effect that instructions may have on visual attention allocation strategies. Although the EMM was designed to minimize a pilot s tendency to fixate on the display, it is reasonable to believe that pilots, in the absence of specific training/instructions, would be naturally attracted to the presence of a new, dynamic and visual appealing display, and thus might over-attend to the display. To underscore the importance of developing appropriate attention allocation instructions and training strategies, we provided one group of pilots with detailed instructions on how and when the display should be used and compared their visual attention behaviors to another group of pilots who received no usage instructions. We expected that the group receiving the instructions would show a decrease in the percent of time visually attending to the EMM relative to the group without instructions.

METHOD

Design

Two factors, Visibility and Instructions, were combined to create a mixed-factorial design. Visibility was manipulated within participants and had three levels (Day VMC, Day 700 RVR, & Night 1,400 RVR); Instructions was manipulated between participants and had two levels (Instructions & No Instructions).

Instructions

The participants that received instructions on how to use the EMM were instructed that it was a secondary navigation aid only to be used when needed, and that control of the aircraft should be accomplished by attending primarily to the out-the-window scene. In addition, participants were provided examples of when the EMM should and should not be used.

Participants

A total of 12 commercial line pilots, each with taxiing experience, participated in the study.

Simulation

Participants were given nine trials in which they taxied from the terminal to the runway at Chicago s O Hare airport in a Boeing 737 part task simulator. The forward out-the-window (OTW) scene was projected on 6 high by 8 wide rear projection screen located 8 from the participants eye point. The side OTW scenes were displayed on two 19 monitors, one on each side of the participant. The EMM, shown in Figure 1, appeared as an 8 x 6 approximately 3.5 from the participants eye point.

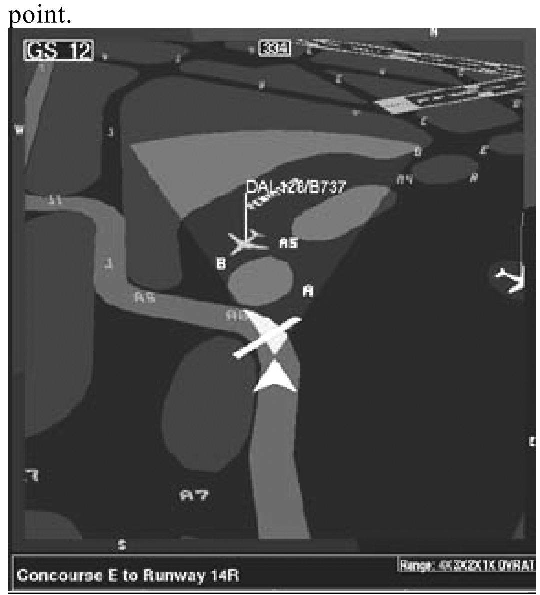

Figure 1. Electronic Moving Map.

Eye Tracking Measures

Eye tracking data was collected using an Applied Sciences Laboratories (ASL) Series 5000 Integrated Eye/Head tracking system, shown in Figure 2 below.

Figure 2. ASL Series 5000 Integrated Eye/Head tracking hardware.

Procedure

When participants arrived, they were first given a consent form and demographic form to complete. Then they were instructed as to their main task; that is, to taxi safely and efficiently from terminal to runway. Those participants receiving EMM usage instructions were given them at this time.

Next, participants were given time to practice taxiing the part-task simulator while the experimenter explained the aircraft s controls and EMM features. After the participants felt comfortable with the EMM and aircraft controls the eye/head tracker was calibrated and the nine experimental trials began.

RESULTS

To analyze the data, several mixed-design full-factorial Analyses of Variance (ANOVA) were conducted. For the eye tracking data, a 3 (Visibility) x 2 (Instructions) analysis was conducted, except for average fixation time, which required a 3 (Visibility) x 2 (Instructions) x 2 (Dwell location) analysis. Instructions was a between-participants variable, while Visibility and Dwell Location were within-participants variables. Studentized Newman-Keuls post hoc tests were conducted (alpha=0.05).

Performance Data

The performance data regarding percent time on route, average moving speed, navigation errors, planning time, and EMM range level use was compared to studies utilizing previous versions of the EMM implemented in this study and found to be similar (McCann et al., 1996; 1997, Mejdal and Andre, 1996). For example, average moving speed in this study was 15.2kts and in McCann et al. (1996) it was 15.9kts. Route accuracy and moving speeds were highest in the Day 700 (low visibility) condition, although differences between the three conditions were very small and not statistically significant.

Eye Tracking Data

Percent time dwelling on the EMM. There was a main effect of Visibility, $\underline{F}$ (2,20) = 3.96, $\underline{p} < .05$. A post hoc test of this main effect showed that percent time dwelling on the EMM was significantly higher for Day VMC (41.3 %) than for Day 700 RVR (37.7 %), but not significantly higher than Night 1,400 RVR (39.4 %). There was no significant difference, however, between Day 700 RVR and Night 1,400 RVR. There was no main effect for Instructions, although a strong trend in the data showed that instructed pilots spent 35% of the time dwelling on the map, while those not instructed spent 44% of the time dwelling on the map. There was no Visibility x Instruction interaction.

Number of dwells on the EMM. There were no significant main effects or interactions across all factors. However, there was a trend showing a potential effect of instructions whereby the instructed pilots dwelled on the EMM an average of 85 times, while those not instructed dwelled on the EMM an average of 122 times.

Mean dwell time. There was a main effect of dwell location (OTW vs. EMM), $\underline{F}$ (1, 10) = 8.19, $\underline{p} < .05$. The average fixation time was longer when dwelling OTW (2.1 seconds) than when dwelling on the EMM (1.4 seconds). There was also a main effect of Instructions, $\underline{F}$ (1, 10) = 5.65, $\underline{p} < .05$. As shown in Figures 3a and 3b, the average OTW fixation time was longer for those participants that received EMM usage instructions (2.1 seconds) than for those that did not (1.4 seconds). Interactions were found for dwell location by Instructions, $\underline{F}$ (1, 10) = 4.99, $\underline{p} < .05$, and Visibility by dwell location by Instructions, $\underline{F}$ (2, 20) = 3.49, $\underline{p} < .05$.

A post hoc analysis on the dwell Location by Instructions interaction revealed that receiving EMM usage instructions significantly increased average dwell time OTW.

Post hoc analysis on the three-way interaction showed that in addition to EMM usage instructions significantly increasing average dwell time OTW, visibility significantly affected average dwell time on the EMM for the group that received EMM usage instructions. For that group, average dwell time on the EMM was significantly higher in Day VMC (1.5 seconds) than in both Day 700 RVR (1.4 seconds) and Night 1,400 RVR (1.4 seconds).

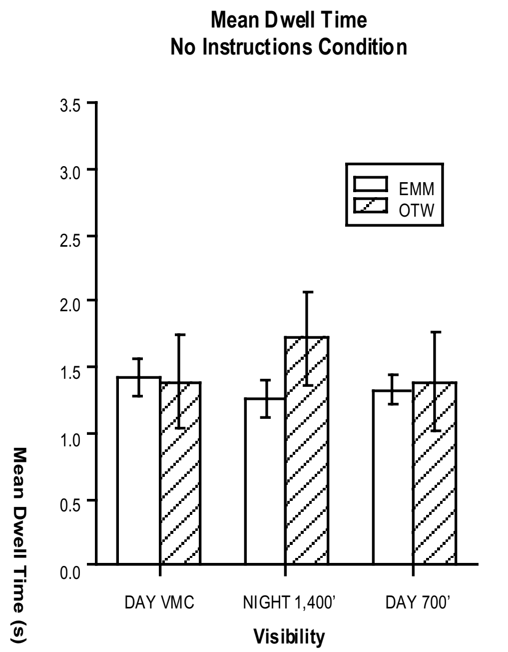

Figure 3a. Means with Standard Error Bars for No Instructions Condition Average Dwell Time.

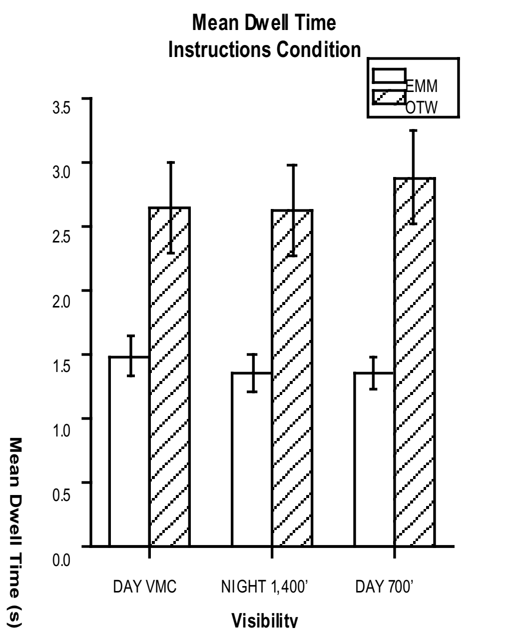

Figure 3b. Means with Standard Error Bars for Instructions Condition Average Dwell Time.

DISCUSSION

Performance Data

All of the performance measure results were similar to the findings of previous studies on the T-NASA EMM. Clearly then, the answer to the question, Did the eye tracker affect the participant s behavior? is No, allowing further analysis and discussion of the eye tracking measures. In addition, the percent time of trial dwelling on the EMM and mean dwell time data from this study utilizing single pilots in a part-task simulator are similar to data collected by Battiste et al. (1996) on percent time of trial heads-down and mean heads-down time utilizing crews in a full-mission simulator. This provides further confidence that our methods did not affect the participants normal taxi behavior.

Eye Tracking Data: Percent Time Dwelling

The results indicate that Visibility significantly affected the amount of time the pilots dwelled on the EMM, with it being significantly higher in Day VMC than in Day 700 RVR (i.e., under higher visibility conditions). In other words, as visibility degrades the pilots spend more time eyes-out and less time dwelling on the EMM with no loss in taxi performance. A potential explanation for these surprising results is that the pilots need to be eyes-out to maintain lateral and directional loop closure, scan for hazards, and maintain information gathering OTW. This explanation is supported by the increased percent time on route found in the performance data as the visibility decreased. This appears to represent the elusive free lunch , in that when visibility degrades, the EMM benefits performance the most, but without additional visual attention requirements. Thus, as intended, it appears that the pilots used the map as a secondary navigation aid across all visibility conditions.

The eye tracking data showed that those pilots receiving EMM usage instructions had a lower mean percent time of trial dwelling on the EMM (35%) than those not receiving instructions (44%), yet this difference did not reach statistical significance.

Eye Tracking Data: Number of Dwells

Despite the absence of significant main effects or interactions, the Instructions variable yielded insightful results. Those participants receiving EMM usage instructions had a lower mean number of dwells on the display.

Eye Tracking Data: Mean Dwell Time

The mean dwell time OTW for the instructions group was significantly longer than those not receiving the EMM usage instructions. Moreover, the ratio of dwell time OTW to dwell time on the EMM was higher for the instructions group. Thus, by providing participants instructions on how the display is to be used, we were able to alter their behavior in comparison to those not receiving usage instructions. These findings suggest that training is a critical factor in the proper use of the EMM.

These data however do not support the Visibility hypothesis that as visibility degrades mean dwell times on the EMM would increase. In fact, the opposite was found for those participants receiving EMM usage instructions.

SUMMARY

The present findings suggest that the EMM is capable of increasing airport throughput in low-visibility environments while not compromising allocation of visual attention. The data show performance levels consistent with previous EMM studies in tandem with an increase in visual attention OTW as visibility degrades and time of day progresses.

Further, these data point to the importance of procedural training. While the EMM was designed to serve as a secondary navigation aid and to promote eyes-out behavior, this objective is mediated somewhat by the training provided.

Future Research

While the results from this study were encouraging, we need to continue to study the effect of visibility, weather, training, procedural issues and situation awareness on both performance and behavior in the context of the EMM. Different training regimes and operating procedures should be developed and compared.

CONCLUSION

This study was a preliminary behavioral assessment of pilot visual attention while using an EMM for taxiing under various levels of visibility and training. The results suggests that implementing Electronic Moving Map displays for low-visibility surface operations should not have a negative impact on allocation of pilot visual attention in either low- or high-visibility conditions. The data also suggests that training is necessary to assure proper usage of, and optimal visual attention interaction with, the EMM.

This study has been an informative and positive beginning to a series of studies that need to conducted to fully understand the allocation of visual attention in varying levels of visibility while using an EMM. It has also been an insightful first step in investigating the effects of training on EMM use.

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