THE INFLUENCE OF CALLOUTS ON PILOT VISUAL ATTENTION TO AN ELECTRONIC TAXI MAP

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## ABSTRACT

NASA's Taxiway Navigation and Situation Awareness (T-NASA) in-cockpit Electronic Moving Map (EMM) has been found to improve the efficiency and safety of airport surface operations. Its design also leads to a paradox: The EMM requires the pilot to look head-down into the cockpit, diverting attention away from the primary, out-the-window (OTW) view. The present study examined the potential benefits of pilots attending to the EMM only when directed by either audio or visual "head-up" callouts. During a medium fidelity, part-task ground taxi simulation, callouts presented were in either a general ("check map") or specific ("turn right onto Bravo") form. Performance and behavioral eye-tracking data revealed that the presence of callouts, especially audio specific, reduced the visual attention demand of the EMM, while maintaining the same level of taxi efficiency and improved levels of incursion detection performance relative to the no-callout condition.

## INTRODUCTION

Ground taxi is an essential element affecting the flow rates at airports. Poor weather, overcrowding and delays pose many challenges to accomplish this task. In an effort to increase terminal area productivity in low-visibility conditions, NASA developed the T-NASA (Taxi Navigation and Situation Awareness) cockpit suite. One of its components is an Electronic Moving Map (EMM) (see Figure 1) that was developed in an attempt to provide situation awareness, reduce workload, and increase pilot confidence while taxiing in low-visibility conditions.

### The EMM Paradox

While taxi performance in a low-visibility, high attentive demand environment has already been found to benefit from the use of an electronic map display (McCann, Andre, Begault, Foyle, & Wenzel, 1997, McCann, Foyle, Hooey, Andre, Parke, & Kanki, 1998), the EMM design brings with it a paradox: The EMM affords a head-down, eyes-in position of gathering information from the map at a time when it is important for pilots to be head-up, scanning the OTW view. Thus, the EMM can lead to superior taxi performance, but its design also encourages a head-

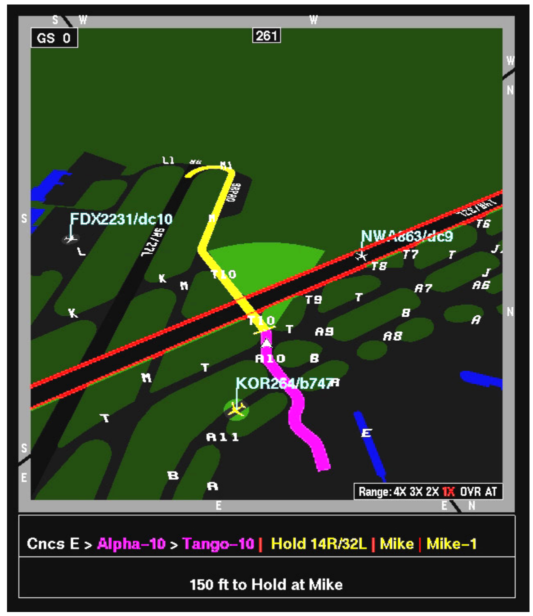


Figure 1. Electronic Moving Map (EMM)

down eyes-in behavior at a time when it is crucial for the pilot to be looking OTW. Accordingly, it is critical that the information presented on the EMM supports the optimal allocation of visual, attentional, and cognitive resources.

Lasswell and Wickens (1995) propose that the aircraft taxi task is actually comprised of two subtasks: local guidance (which includes information gathering from both inside and outside the aircraft) and global awareness (which includes information almost exclusively gathered outside the aircraft). Both of these subtasks require a division of attention between the head-up OTW and the head-down instrument display domains during ground taxi operations. Thus, it is important to integrate related information acquired from both domains in order to reduce cognitive processing demands upon the user.

### Behavioral Issues

Performance benefits brought by the EMM are well documented, however the behavioral issues of how pilots interact with the EMM are still largely unknown. During development of the T-NASA EMM, a major concern was the potential for pilots to use the display for aircraft control (rather than navigation), staying head-down and eyes-in during low-visibility conditions.

The first T-NASA study specifically examining pilot visual attention to the EMM was conducted by Graeber and Andre (1999). They sought to increase visual OTW attention and decrease head-down time attending to the EMM by the introduction of usage instructions. These usage instructions informed the pilots that the display as designed was to be used as a secondary navigation aid to eyes-out taxi, not a primary centerline tracking display. The data gathered showed that pilots use their scanning strategies to view the EMM efficiently whether given usage instructions or not, and under both high- and low-visibility conditions. Still, providing instructions on EMM usage did significantly alter user behavior, showing 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).

Attention Callouts

A potential method for avoiding this utility-visibility paradox is the use of attention cueing, or callouts. It has been shown that prior knowledge of a target position (cueing) facilitates performance for a briefly presented target (Posner, 1980). This is the reasoning behind the use of a callout. A callout is defined as an attentional or informational cue designed to provide the pilot with a cueing mechanism for attention to be directed to, in this case, the head-down EMM. The goal of the callout is to change attention to the EMM from an internal, self-based, goal-driven process to one of an external, event-based, stimulus-driven process. A secondary goal of the callout is to eliminate the operator s reliance on using potentially erroneous user-defined expectancies to drive their visual scanning processes.

The Present Study

The objective of the present study was to compare auditory vs. visual callouts, as each has potential benefits and costs well-documented in the literature. In addition to the callout modality, we examined the effects of the specificity, or informativeness, of the callout. Two levels of callout specificity were implemented. A general callout simply signaled to the pilot that some event or condition exists that warrants his or her attention to the EMM. This is likened to a general caution indicator in an automobile or aircraft. A specific callout provided information as to the specific nature of the event or condition (e.g., You are off route ).

METHOD

Two independent variables were manipulated in a within-subjects design. Callout Mode was varied over two levels: visual and auditory. Callout Specificity was varied over two levels: general and specific. The current method of using the EMM with no callout was included as a control condition. These factors combine to create five experimental conditions: 1) control condition with no callouts, 2) visual general callout, 3) visual specific callout, 4) auditory general callout, and 5) auditory specific callout.

A total of 15 commercial line pilots, five captains and ten first officers, all with taxiing experience, participated in the study. Participants were given 25 total trials, five trials per experimental condition, in which they taxied from terminal to runway at Chicago O Hare airport in a Boeing 737 part task simulator. Taxiing visibility was set at 700 daytime RVR. There were 127 general callouts and 179 specific callouts over the 25 trials. The forward OTW scene was projected on a 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 appeared as an 8 X 6 display on a 17 monitor 3.5 from the participants eye point. Eye tracking data was collected using an Applied Sciences Laboratories (ASL) Series 5000 Integrated Eye/Head tracking system.

Callout modes. To support processing of the visual callout while maintaining a head-up, eyes-out posture, the visual callout was presented on a head-level Visual Callout (VC) display (see Figure 2) akin to the location of the mode control panel on most commercial aircraft.

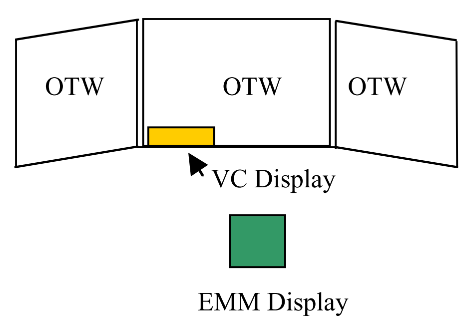


Figure 2. Layout of visual callout display.

The audio callouts consisted of a voice recording that would speak the words instead of textualizing them.

Callout events — turns and holds. A list of callout events and callout language is shown in Table 1. For visual callouts, the text message that appeared on the VC for general callouts regarding upcoming turns consisted of the two words Check Map . For upcoming holds and their accompanying proceed from holding messages the text consisted of Hold Short and Proceed Across .

The text messages that appeared on the VC for specific callouts consisted of the following: Turn Left/Right onto next intersection/runway (e.g., Turn Left onto Bravo 3 ), Hold Short of next intersection/runway (e.g., Hold Short of Bravo 3 ), and Proceed Across next intersection/runway (e.g., Proceed Across Bravo 3 ). For audio voice callouts, messages that were spoken in the cockpit by the T-NASA system consisted of the same words that made up the visual callouts.

Callout events — preplanned incursions To evaluate safety aspects and the effectiveness of the EMM display with and without callouts, potential runway incursions were investigated. When traffic was within 1250 ft. and on an intercept course with the ownship (OS), a Traffic Advisory callout was given for general callouts, while Traffic Advisory, Traffic on Left/Right was given for specific callouts. If the traffic aircraft remained on an intercept course with the OS and came within a 5 second time to impact or either a general callout COLLISION WARNING or specific callout COLLISION WARNING, TRAFFIC ON LEFT/RIGHT would be given. The incursion callout mode (visual or auditory) presented would match the mode that the turn/hold mode presented.

Impact from the incurring aircraft would be avoided only by correctly responding to the warning logic on the EMM (traffic symbol turns red and begins to flash) or holding short when instructed to do so. Located on the subject s left was a joystick/tiller, which steered the front nose wheel. There were also two buttons located on top of the tiller, right and left. The correct response to the warning callouts was to press the corresponding button that the traffic incursion was coming from during the 5-second collision warning callout. The incurring aircraft will be given a hold bar and stopped, and the subject would be given a message to proceed. If the subject did not press the proper button in the allotted time, the OS was given a hold bar and the incurring aircraft was allowed to proceed.

Table 1
Callout Events and Text/Audio for General and Specific Conditions

| **Event Type** | **General Callout** | **Specific Callout** |
|---|---|---|
| Turn Ahead | Check Map | Turn Left/Right onto <Location> |
| Hold Short | Check Map | Hold Short of <Location> |
| Proceed Across | Check Map | Proceed Across <Location> |
| Traffic Advisory | Traffic Advisory | Traffic Advisory, Traffic on Left/Right |
| Collision Warning | Collision Warning | Collision Warning, Traffic On Left/Right |

RESULTS

To compare the callout modes against the baseline of no callouts given, a single factor, 5-level ANOVA was performed. Alpha for all ANOVA s and post hoc tests was set at .05.

Taxi Performance Data

Percent time on route, average moving speed and navigation errors made were not influenced by the presence or absence of callouts. The callouts were effective, however, in improving incursion detection performance relative to the baseline condition.

Missed incursion responses. There were 75 preplanned incursion trails, with 5 incursion incidents per subject, 1 per each block of 5 trials. Out of the 75 incursion incidences, 8 were not responded to (see Table 2).

The ANOVA for the number of missed incursion responses was significant, $\underline{F}$ (4, 56)= 5.44, $\underline{p}$<.01. This shows the number of missed incursions in the baseline (no callout) condition was greater than any of the callout conditions. A separate 2X2 ANOVA found no significant differences between the callout conditions.

Table 2
Missed Incursion Responses per Condition

| Condition | No callout | Visual general | Visual specific | Audio general | Audio specific |
|---|---|---|---|---|---|
| Missed incursion responses | 6 | 0 | 0 | 1 | 1 |

Behavioral Eye-Tracking Data

The results showed that pilots spent a lower percentage of time attending to the EMM when any callout was presented, relative to the baseline condition. Likewise, the number of dwells on the EMM over the course of an entire trial showed a non-significant trend decrease with the inclusion of callouts.

Percent of trial dwelling by location. The ANOVA for percent of trial dwelling OTW did not reveal a significant main effect, $F < 1$. The percent of trial dwelling on the EMM did reach significance, $F(4, 56) = 2.54$, $p<.05$.

The findings of percent of trial dwelling by location generally reflected the amount of time pilots attended (looked) OTW versus at the EMM. With the inclusion of callouts, percent dwell OTW went up while percent dwell on the EMM went down (see Table 3).

Table 3
Percent of trial dwelling by location per condition

| Condition | No callout | Visual general | Visual specific | Audio general | Audio specific |
|---|---|---|---|---|---|
| % dwell time OTW | 0.49 | 0.50 | 0.51 | 0.51 | 0.53 |
| % dwell time EMM | 0.36 | 0.33 | 0.32 | 0.32 | 0.31 |

Number of dwells by location. The ANOVA for the number of dwells OTW did not reveal a significant main effect, $F < 1$, similar to the main effect for number of dwells on the EMM, $F = 1.86$, $p = .13$. The number of dwells on the VC did reach significance, $F(4, 56) = 16.43$, $p < .01$, however this is to be expected as there is no visual callout under the audio callout conditions.

Despite not finding a significant main effect, we can look at the means from the analysis and extract some usage patterns, best revealed in Table 4 below. Note the difference in number of dwells OTW vs. the EMM is higher for the callout conditions than the no callout. Specific visual and audio callouts showed the greatest differences compared to the baseline of no callouts.

Table 4
Mean Number of Dwells by location per Condition

| Condition | No callout | Visual general | Visual specific | Audio general | Audio specific |
|---|---|---|---|---|---|
| # dwells OTW | 133.59 | 132.86 | 136.38 | 138.71 | 130.57 |
| # dwells EMM | 119.67 | 111.09 | 110.10 | 115.23 | 105.88 |
| Difference | 14 | 21 | 26 | 23 | 25 |

Zoom level usage. The T-NASA EMM has 5 user-selectable zoom levels that can be switched at any time during the ground taxi task at the pilot s discretion. The views to choose from include four 3-D perspective views from an eye point above and behind the ownship position, ranging from a 1X farther out view to a relatively close-up 4X view (see Figure 1). The ANOVA for percentage of zoom level used per condition did not reveal a significant main effect for any zoom level.

Although significant main effects or interactions were not found, we can look at the means from the analysis and extract some zoom level usage patterns (see Figure 4). With the addition of callouts, the means for percentage of zoom level used for the 1X, 2X, and 3X levels tended to slightly increase (especially the 3X visual and audio specific callouts), while the 4X level use decreased among all conditions.

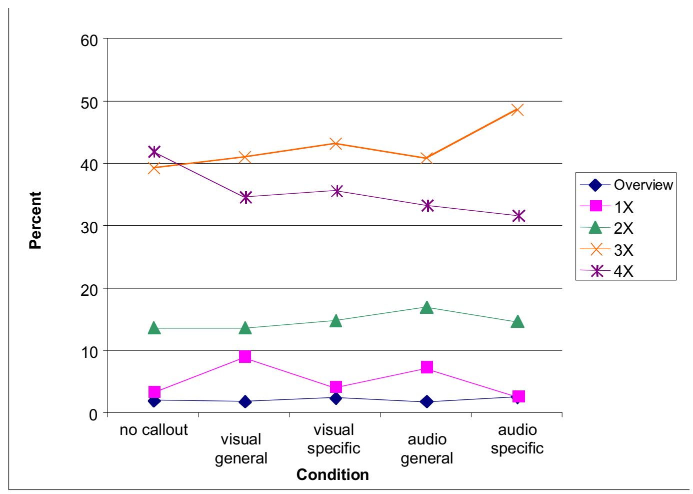


Figure 4. Zoom level use by condition.

Subjective Survey Data

The subjective survey data was gathered from questionnaires using a Likert scale with a range from 1 to 7, with 1 representing the lowest amount of the variable in question (e.g., workload), and 7 representing the highest amount. Pilots stated that, with the presence of callouts, their workload and amount of head-down time significantly decreased, while their situational awareness and utility increased.

Head-down time. For the amount of head-down time each subject felt they experienced per condition, the ANOVA showed a significant main effect, $F(4, 56) = 5.260$, $p < .01$. The mean values suggest that the pilots felt their head-down time was reduced with the callouts relative to the baseline condition, with the lowest rated amount of head-down time in the audio specific condition.

Workload. For the overall workload pilots experienced while completing their taxi task, the ANOVA showed a significant main effect, $F (4, 56) = 3.09$, $p < .01$. Again, the data show a general decrease in workload with the inclusion of any type of callout, with the greatest reduction in the audio specific condition.

Situational awareness. The ANOVA did not find a statistically significant main effect, $F (4, 56) = 1.40$, $p = .25$. Still, the mean tendency suggested that pilots felt they had greater situational awareness with the use of a callout as opposed to no callout presented at all.

Utility. In a post-trial survey asking subjects to compare the utility or usefulness of the callout types presented, the two specific callout types were found to be of greater use to the pilots than those with general specificity. The ANOVA revealed a significant main effect, $F (4, 56) = 4.93$, $p < .01$. An additional 2X2 ANOVA found the specific callout conditions to be rated higher than the general callout conditions, $F (1, 14) = 12.80$ $p < .01$.

## DISCUSSION

In reviewing and interpreting the data, it was found that while not all of the hypotheses were supported, the results generally pointed to the fact that callouts positively affected pilot performance, visual attention and subjective workload.

### Performance Measures

As expected, the average taxi speed and percent time on route did not change with the inclusion of callouts. However, the inclusion of any type of callout was successful in reducing the number of incursion responses missed by a significant 60 percent over the no callout baseline. During a post-experiment debrief one participant in this study said he liked the EMM with the (specific) callouts because it directed his scan and freed him to look OTW more.

### Behavioral Measures

The results of the behavioral measures were in general accordance with our hypotheses. In regards to the EMM, we predicted that the addition of callouts would direct more visual attention OTW, thereby decreasing both the number of EMM eye dwells and the percentage of EMM eye dwell time. Findings suggested that with any type of callout subjects attended OTW for a greater percentage of trial time, while simultaneously subjects attended to the EMM a smaller percentage of trial time.

Zoom level usage. With the presence of callouts, the zoom level usage increased for the percentage of trial allotted to the 3X zoom level while the 4X level use decreased. Post-study interviews revealed that pilots felt that with a callout they did not require as much time to gain the same near distance information that the closer 4X level affords. Subsequently, they could spend more time at the farther out zoom level of 3X and gain better situational awareness by seeing more of the airport surface on the map.

### Subjective Measures

Four of the subjective variables measured showed significant effects indicating a positive effect of the callouts: head-down time and workload means decreased, while situational awareness and utility means increased with callouts. Similar to the behavioral measures, the greatest measured effect was under the audio specific condition.

Other human factor studies suggest that paradoxically, increasing automation on the flight deck occasionally increases pilot workload (e.g., Damos et al., 1999). In this experiment, however, subjects said their workload for completing the taxi task went down with the inclusion of the callouts presented. In addition, subjects felt the amount of head-down time they spent scanning the EMM lessened. When pilots were asked at the conclusion of the experiment about the utility of the callouts, they stated that they would much rather have a callout of any type than none at all.

### Callout Modality and Specificity

Across most measures of performance, behavior (visual attention) and subjective ratings, the results showed the greatest benefits for the audio specific condition. For example, post-hoc pair-wise ANOVAs for the audio specific condition vs. the no callout baseline condition showed the number of dwells and the percent of trial dwelling on the EMM significantly decreased.

Callouts given by voice theoretically have the potential to increase the head-up time looking at the OTW display while decreasing time spent head-down looking at the EMM. Wickens (1992) argues that modality separation of concurrent tasks can make time-sharing in working memory more efficient. Thus the task of taxiing the airport surface a visual task and processing the audio callouts an auditory task, are more easily time-shared relative to the condition where a visual callout is presented. The difference in modality of information sources might explain much of the advantages shown by the audio specific condition.

Limitations

Lee et al. (1999) pointed out that command messages (e.g., turn right here ) can lead to an automation bias (Mosier, Skitka, & Heers, 1996). For example, command messages can reduce certain information processing requirements of the driving task, but it also has the potential to misdirect drivers should the command fail to consider all the relevant factors. Thus, there is a potential for command type cues, such as the specific callouts used in the present study, to be blindly acted upon; a situation that can be problematic if the callouts are unreliable or erroneous. This important issue of blind compliance to specific (command type) callouts was not directly examined in this study and should be further investigated in future research.

## CONCLUSION

This study was a preliminary assessment of the influence of audio and visual, general and specific callouts on pilot visual attention while using an EMM for taxiing in low-visibility conditions. The potential for pilots to use the EMM for aircraft control and rely too heavily on the display was the primary impetus for the study. The results suggest that the inclusion of callouts better affords proper usage of the display as a secondary navigation aid in that the callouts direct visual attention OTW while producing shorter glances at the EMM. Callouts also aided pilots in detecting and responding to critical events, such as incursions.

The attentional process of currently taxiing with or without an EMM is more internally goal-driven, with user-defined scanning and repeated, frequent glances. The use of callouts in conjunction with an EMM and the T-NASA system made the navigation task a more external, event-driven process and reduced the need for pilots to constantly scan the EMM looking for events. Audio specific callouts generally showed the greatest benefits across the various dependent measures; however, the presence or absence of callouts had a greater effect than the level of specificity, and to a large extent, the modality as well.

Overall, the introduction of attentional callouts for EMM produced the venerable free lunch effect, defined as gaining something for nothing. The callouts had the effect of reducing visual attention to the EMM while at the same time improving route navigation and response to incursion events. We are confident that the use of attentional callouts can be an effective method for maximizing the utility of the EMM display, while minimizing the visual attention impact during the critical taxi phase.

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