

# INTERFERENCE TIMING AND ACKNOWLEDGEMENT RESPONSE WITH VOICE AND DATALINK ATC COMMANDS

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Datalink is a text system used to send messages between ATC and pilots. There are concerns related to changes in information processing demands and responses associated with executing speech and text ATC commands. The timing of interference and the acknowledgement response on command execution performance were examined during the processing of simulated ATC commands. Verbal and central executive (CE) interference tasks were presented before or after the acknowledgement. Participants received both speech and text commands, responded by a verbal or manual acknowledgement, and set the controls in a flight simulator. Results demonstrated an advantage for a manual acknowledgement with longer messages. CE as opposed to verbal interference prior to an acknowledgement had a greater negative effect that was exacerbated in the text condition. The findings are interpreted within the context of a working memory and multiple-resource perspective and implications are discussed with regard to communication processes in aviation.

## INTRODUCTION

Datalink is a technology that presents ATC messages as text (Kerns, 1991; Navarro & Sikorski, 1999). The primary advantages of datalink include reduced radio congestion, gating messages directly into aircraft flight systems, and permanence of the text display. However, datalink changes the nature of ATC-pilot communication in several important ways. First, pilots must read rather than listen to messages. Second, acknowledging a datalink message requires a manual button press rather than a verbal readback. Third, there are inherent delays with datalink because of the time required to uplink and downlink information to ATC. During these time delays, other tasks are performed by both pilots and controllers (Lozito, McGann, & Corker, 1993). Last, pilots are susceptible to distraction from processing other sources of information in the cockpit that can adversely affect the comprehension, acknowledgement, and execution of voice ATC commands.

Recently, Risser and colleagues performed a series of studies that examined how individuals recall and execute simulated radio and datalink commands (Risser, McNamara, Baldwin, Scerbo, & Barshi, 2002; Risser, Scerbo, Baldwin, & McNamara, 2003; Risser, Scerbo, Baldwin, & McNamara, 2004; Scerbo, Risser, Baldwin, & McNamara, 2003). The theoretical framework for this research draws upon the working memory model of Baddeley and Hitch (1974) and Wickens' (1984) multiple-resource model (1984). Specifically, Baddeley and Hitch's (1974) working memory (WM) model posits

three components of working memory: a central executive (CE) component responsible for controlling attention and decision processes, a visuo-spatial sketchpad for visual and spatial processing, and an articulatory loop for phonological (e.g., verbal) processing. Wickens' (1984) multiple resource theory (MRT) makes finer distinctions regarding the input and output codes where the information-processing channel (auditory or visual), type of code (spatial or verbal), and processing stage (cognitive or response) each draw upon separate resources. In general, the WM model addresses information storage and MRT addresses information processing. However, both theories predict that when two tasks draw on the same pool of resources, there is a greater opportunity for performance decrements than when tasks draw upon separate resources.

The primary findings described by Risser and his colleagues (Risser et al., 2002; Risser et al., 2003; Risser et al., 2004, Scerbo et al., 2003) showed that the input modality (i.e., visual versus auditory) of verbal information (i.e., text or speech) was less important than the nature of the interference because both text and speech utilize an underlying verbal processing code. By contrast, sources of interference that compete for control of attention or decision making (e.g., central executive resources) and those that require the use of the phonological loop (e.g., verbal resources) were more problematic because they disrupt the rehearsal process in memory. Furthermore, when errors in performance occurred, they appeared during the presentation of text information especially when there was greater demand on working memory or additional visual scanning

requirements. Their results validate a concern regarding the maintenance of speech and text information in working memory and its susceptibility to various sources of interference. However, in these previous studies interference was restricted to the encoding stage of processing.

The present investigation addressed the joint effects of processing stages and codes during the receipt, acknowledgement, and execution of ATC commands. Specifically, the effects of acknowledgement response and interference timing on command execution performance were studied during the communication process. Participants were presented with different numbers of commands in both speech and text formats and had to set controls in a flight simulator; however, they had to acknowledge the messages prior to execution with either a manual or verbal response.

It was expected that a verbal acknowledgement would interfere with commands in working memory more than a manual acknowledgement because both would utilize a verbal processing code and according to Wickens (1984), they would draw upon the same pool of resources. Regarding interference timing, interference *before* acknowledgement was expected to result in poorer performance than interference introduced *after* acknowledgement because Baddeley, Chincotta, and Adlam (2001) showed that additional task switching requires more resources. Further, an interaction was expected between acknowledgement response and message format where verbal acknowledgement would have a greater detrimental impact on text than speech because text does not have direct access to the phonological loop (Schneider, Healy, & Barshi, 2000).

## METHOD

### Participants

Thirty-two graduate students participated and were paid \$30 each. There were 14 male and 18 female participants whose ages ranged from 22 to 39 ( $M = 26.6$ ).

### Apparatus

*Flight simulator.* An X-Plane 7.30 flight simulator was used as the cockpit display. Heading, speed, and altitude controls on the mode control panel were manipulated using the mouse.

*CDU.* A mouse-controlled simulated control and display unit (CDU) was designed with moderate fidelity and incorporated relevant menu systems and working buttons to handle incoming text messages.

### Stimuli

*Commands.* Simulated speech and text ATC commands were presented as one-, two-, and three-command messages. In both speech and text message formats, commands were presented as complete three-word phrases in a verb-object-indirect object syntax (e.g., change heading 180). Text messages were presented on the simulated CDU screen and presentation times were equated with speech commands of the same message length.

*Interference tasks.* Two interference tasks were used. The verbal interference task required participants to listen and identify their aircraft call sign (e.g., Alpha-Four) and respond by pressing the spacebar on the keyboard. For each trial, there were a total of seven stimuli containing three targets and four distractors.

The CE task required participants to perform mental arithmetic to calculate a series of simple fuel algorithms. The fuel status display in the simulator showed the total fuel remaining and the fuel flow for each engine. Participants had to answer the question, "At the current fuel burn, how much total fuel will remain after one more hour?"

Last, a control condition was included in which there was no interference task. In this case, there was no time delay prior to or after acknowledgement. Therefore, participants immediately acknowledged a message and executed the commands. Completion time for each interference task was approximately 14 s.

### Design

The experiment used a full factorial within-subjects  $2 \times 2 \times 3 \times 3 \times 2$  design that included message format (speech, text), interference type (verbal, CE), message length (1, 2, 3), interference timing (before acknowledgement, after acknowledgement, and none), and acknowledgement response (verbal, manual).

Each trial included a factorial combination of message format, interference type, interference timing, acknowledgement response, and message length. There were two experimental blocks with 72 trials per block.

### Procedure

Participants completed two separate experimental sessions (addressing speech and text) within 48 hours and received training prior to each session. Participants were presented with one, two, or three commands requiring an acknowledgement response that alternated with the interference task (verbal or CE) when present. Participants heard the commands in the speech condition. In the text condition, a chime sounded and

the commands were displayed on the CDU. Participants were required to acknowledge messages by either performing a verbal readback or manually pressing a key on the CDU. After acknowledgement and completing the interference task, participants set the controls on the simulator display. Participants were instructed to manually execute the commands by correctly setting the simulator controls in the same order as they were presented in the command set.

## RESULTS

Although participants were asked to maintain order when setting the controls, only the data recorded without the order restriction are presented here. The proportion of controls correctly set (CS) was the primary dependent measure and the data were analyzed using a repeated-measures ANOVA with an alpha level of .05 for statistical significance. Tukey post hoc comparisons were used to compare means.

A 2 (format) x 2 (interference) x 2 (response) x 3 (timing) x 3 (length) ANOVA was performed on the CS measure. The analysis revealed several significant main effects and interactions; however, due to space limitations, only the higher order interactions are presented.

A 3-way interaction was observed among format, message length, and acknowledgement response,  $F(2, 62) = 4.920$ , (see Figure 1).

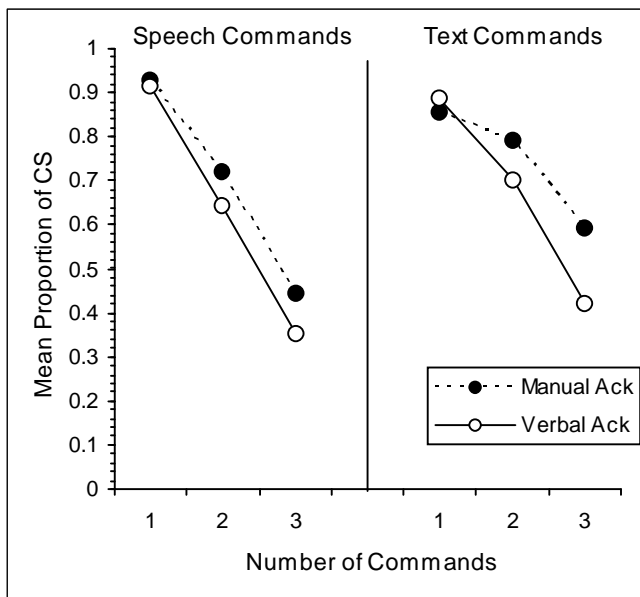


Figure 1. Mean proportion of CS for each format and acknowledgement response as a function of message length.

Overall, CS declined as the number of commands increased. Post hoc comparisons among the means

demonstrated a difference between formats for manual acknowledgements where there was a lower proportion of CS with one command in the text as compared to speech condition. Further, there was a lower proportion of CS in the speech condition with two and three commands compared to text. Also, verbal acknowledgements resulted in a lower proportion of CS in both speech and text conditions and the magnitude of these differences was more pronounced when messages were presented as text.

A significant 4-way interaction was observed among format, interference timing, message length, and interference type,  $F(4, 124) = 2.670$ , (see Figure 2).

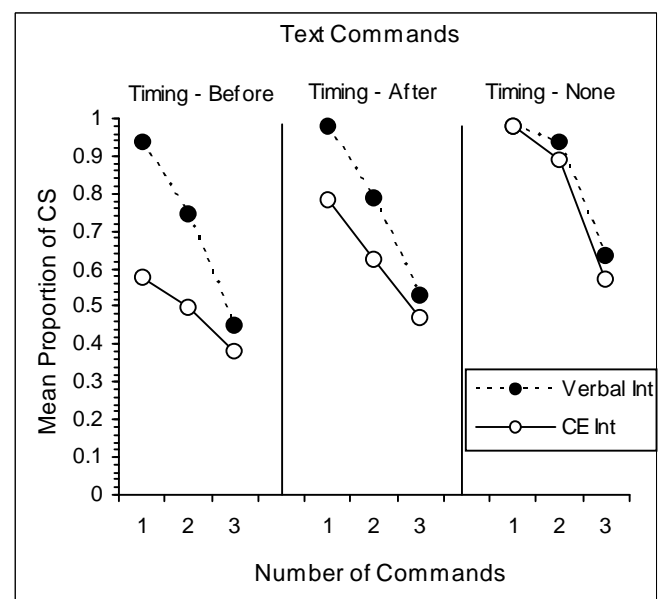
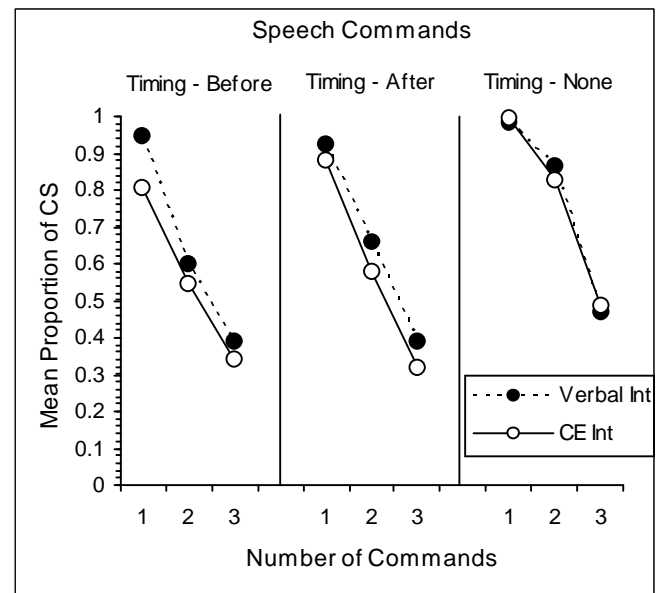


Figure 2. Mean proportion of CS for each format, level of interference timing, and interference type over message length.

In both speech and text conditions, there was a lower proportion of CS as message length increased within both verbal and CE interference. Interference occurring before and after acknowledgement resulted in lower CS as compared to the control condition. CE as compared to verbal interference resulted in a lower proportion of CS, but the magnitude of these differences decreased with an increase in message length. Also, the magnitude of the interference effects increased in the text condition. Specifically, the negative effects of both CE interference and the before timing condition was greater in the text as compared to speech condition.

## DISCUSSION

The introduction of datalink changes the nature of ATC-pilot communication because it requires the processing of text as opposed to speech information and manual instead of verbal acknowledgement responses. Further, the time delays inherent in a datalink environment provide opportunity for interference at different stages of the communication process. The aim of the present study was to address the response portion of the communication process (i.e., acknowledgement and execution) and the timing of interference on command execution performance. This study differed from previous studies of Risser and his colleagues (Risser et al., 2002, 2003, 2004; Scerbo et al., 2003) in two distinct ways. First, the nature of the response, either a manual or verbal acknowledgement, was examined. Second, the timing of interference was presented before or after the acknowledgment response. Risser et al. (2002, 2003) and Scerbo et al. (2003) presented interference during the presentation of commands thereby disrupting the encoding process.

The present study demonstrated that executive processing interference tasks have a greater negative effect on performance than verbal processing interference tasks. However, these differences are attenuated when there is more information in memory. That is, as memory load increases and reaches capacity the source of interference is less important. Furthermore, there is a cost associated with switching tasks because more resources are required to shift attention between separate tasks (e.g., interrupting the communication process by performing an interference task *before* acknowledgement). Therefore, carry-over effects are likely to occur between processing stages and those effects will become more pronounced as resources reach capacity. Although performance was affected by interference type and timing, the impact was less dramatic for acknowledgement response. The results showed that the processing code used for a task had a greater effect on resource capacity than the response

code. It can be concluded that more resources are used to process a task (i.e., store, rehearse, manipulate) in working memory than to respond and this was more evident with CE as compared to verbal interference. In other words, the central processing code is of greater importance than the response code.

It is important to note that the ATC messages used in the present study were based on a simple prototype of actual ATC messages. They were designed to be consistent with our previous work and could be executed without domain knowledge. Thus, it is possible that the pattern of results observed in this study might differ from those obtained with experienced pilots. However, it is unlikely that even experienced pilots would be impervious to the limitations of working memory and the effects of timing and sources of interference examined in the present study.

For example, consider the following record from the Aviation Safety Reporting System (ASRS), ACN 561950. During a climb to FL370, the pilots became concerned about storms ahead. They contacted ATC for a minor route change and ATC requested they change altitude to FL330. Neither the captain nor the first officer reset the altitude to FL330. The first officer, who was flying, did not hear the amended altitude clearance and therefore did not repeat the information to the pilot per flight crew procedures. The pilots attributed this error to distraction. They were focusing on the new route clearance, entering information into the flight management computer, and monitoring their distance from the storms (ASRS, 2003).

In this incident, the pilots were using executive resources to interpret the new clearance and to evaluate the weather situation in relation to their aircraft. More important, these executive resources were utilized immediately after ATC requested the change in altitude. Given the results of the present study, one could argue the use of executive resources disrupted rehearsal and possibly the encoding of the message. This example highlights the need to understand the role of timing and type of interference during the communication process.

### Implications for Datalink

Our findings suggest at least two implications for datalink. First, the type of information being processed and the order in which it is processed affects the integrity of instructions in memory. This finding may be of more concern with real datalink systems because time delays allow pilots and controllers to distribute their workload and complete other tasks during communication (Lozito et al., 1993). Similarly, pilots may have had difficulty switching tasks and shifting attention in mixed environments with both radio and

datalink (Dunbar, McGann, Mackintosh, & Lozito, 2001). Therefore, the prioritization of tasks is an important concern and suggests that pilots exercise caution when coordinating multiple tasks in sequence.

A second implication is that text appears to be more susceptible to the effects of interference as resources begin to reach capacity. However, the permanence of datalink messages can overcome the memory resource problem. In actual datalink systems, the message is read exactly as sent and is always accessible because it can be stored. The storage aspect of datalink, however, does not preclude the need to investigate text processing because there may be instances when datalink messages must be committed to memory (e.g., if a pilot must navigate a multi-page datalink message it may be necessary to retain information from a previous page in memory). Furthermore, there is another concern surrounding head-down time in a datalink environment caused by the need for pilots to navigate the menu system instead of looking out of the window. Thus, pilots may attempt to remember information from the datalink screen to minimize their head-down time.

Collectively, the findings of the present study indicate that the effectiveness of ATC-pilot communication can be moderated by interference and timing factors and may ultimately affect the execution of commands. The implications of these findings can also be applied to other areas where sequential task prioritization is of concern (e.g., cockpit checklists).

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