A Proposal to the

National Aeronautics and Space Administration
AMES Research Center

For Support of

Data-Link Aircraft Communications: An Examination of Interference, Coherence, and Workload

Name and Address of Institution:	Old Dominion University Research Foundation Post Office Box 6369 800 West 46th Street Norfolk, VA 23508-2010
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Abstract

Recent technology allows Air traffic control (ATC) messages to be sent in textual format via data link, as well as via radio transmission. The purpose of this project is to investigate differences between auditory and textual transmission of information to better predict errors as a function of modality and to ultimately develop a set of guidelines for data link transmission of ATC messages. To this end, we will address three issues: working memory interference, message coherence, and workload. The first issue specifically regards whether different modes of interference (verbal or visual) are more detrimental for data link or radio transmission. We will also investigate differences between interference that occurs concurrently and subsequent to the target task. The second issue regards the effects of coherence of the ATC message. We will compare auditory and textual presentation of data-link messages that vary in coherence on two levels, the word (spelled out vs. abbreviated) and the idea (complete, incomplete). The third issue regards the differential effects of workload on text and speech communications. Moderate workload will involve performing the data-link activities simultaneously with the monitoring task. High workload will involve data-link activities performed simultaneously with monitoring, tracking, and resource management tasks. A high-workload/unpredictable condition will additionally include unexpected failures in the resource management task. Within each of these areas we also investigate effects of message length, urgency, and expectancy. This project will provide valuable information concerning the effects of interference, message coherence, and workload on task completion and comprehension in the ATC environment.

Data-Link Aircraft Communications: An Examination of Interference, Coherence, and Workload

Introduction

Air traffic control (ATC) messages have been typically presented in the auditory modality via radio transmission. However, recent technology allows textual messages to be sent via data link. Data link messages are displayed on a small screen, which is situated at hip level in front of the pilot flying (PF) and the pilot not flying (PNF). In an ideal scenario, the message is read aloud by the PNF to the PF. The PF generally executes the ATC requests. The PNF then sends a message to accept the ATC request by pressing an accept button. This procedure contrasts with radio transmission wherein both pilots hear the ATC message, and acceptance and execution often take place simultaneously. Data link messages solve several problems associated with radio transmission such as message clarity and radio frequency congestion. Data link was also expected to reduce ATC errors and pilot errors. This expectation has not been confirmed. Rather, errors have persisted, though of a seemingly different nature than those associated with radio transmission. Coupled with the additional down-load time, data link messages also typically require 15 to 30 seconds longer to execute than does a radio transmitted message. The purpose of this project is to investigate fundamental differences between auditory and textual transmission of information to better predict errors as a function of modality and to ultimately develop a set of guidelines for data link transmission of ATC messages.

Working Memory Interference

The first issue to be addressed in this project is the effect of interference during and after ATC messages. Concurrent and subsequent interference potentially result from cockpit noise, flight attendants, and subsequent messages. The question to be addressed by our first set of experiments is whether different types of interference (verbal or visual) are more detrimental for data link or radio transmission, and whether the type of interference interacts with presentation modality.

To provide a framework, we turn to Baddeley and Hitch's theory of working memory (Baddeley & Hitch, 1974). Accordingly, working memory is comprised of three components: a central executive responsible for reasoning processes, a visuo-spatial sketchpad for visual and spatial processing, and an articulatory loop for auditory processing of information. The model predicts and research has confirmed that dual tasks in the same modality result in greater interference and performance decrements than do dual tasks that rely on separate modalities. Hence, a visual task will be impaired by simultaneous visual interference, but affected little by simultaneous verbal interference. However, in the cockpit, interference may be not only simultaneous, but subsequent to reading a message. Hence, it is important to understand whether interference after reading an ATC message is more detrimental as a function of the modality of post-task interference. The first set of experiments will be conducted using the standard WM dual-task paradigm. The second set of experiments will include directions to complete a procedural task. The latter set of experiments thus introduces the comprehension and procedural components essential to understanding and executing ATC commands.

General Methodology

Within each of the following three sets experiments, the variables include task type (Verbal, Visual) and interference type (Verbal, Visual). The verbal interference will consist of repeating the word "the" repeatedly, and the visual interference will consist of conducting a visual search task. The first experiment (Experiment A) of each set will compare the standard effects of concurrent interference to no interference; the second experiment (Experiment B) will present post-task interference for 15 or 30 seconds. We expect to replicate previous results showing that the effects of simultaneous interference are greater when the task and interference are of the same modality. We also predict that subsequent interference will show the same trends and that the inhibitory effects of interference will increase as a function of time.

In Experiments 1A and 1B, the verbal task will consist of listening to a list of to-be-recalled words, whereas the visual task will consist of reading silently a list of to-be-recalled words. In Experiments 2A and 2B, the task will consist of listening to a set of directions (e.g., to change settings on a set of gauges). The directions will be presented auditorily in the verbal condition, and will be read silently by the subject in the visual condition. We predict that performance on the procedural task will show greater interference within the visual mode, and that visual interference should exacerbate this effect.

The third set of experiments (Experiments 3A and 3B) will examine the effects of message length, and whether it has a greater effect with verbally or visually presented information. It has been observed that while the data-link medium invites longer messages, they also may cause more problems than shorter messages. To examine this issue, the number of procedural directions that are presented to the subject will vary from between 2 and 6. It is expected that the message length will have a greater effect in the visual modality, and that this effect will increase with visual interference.

Potential contribution

The results from these six experiments will indicate the impact of different types of interference as a function of modality and guidelines concerning the types of interference that should be avoided with data-link messages. These results will also examine whether the effects of concurrent and subsequent interference depend on presentation modality. Finally, the results of these experiments will indicate whether message length is a critical factor to consider in conjunction with task interference.

Message Coherence

One issue regarding data-link communication that has not been addressed in the literature is the impact on comprehension processes of auditory as compared to textual presentation material. One important factor contributing to comprehension is the structure of the text as reflected by its coherence. Hence, the second issue to be addressed in this study is whether the completeness, or coherence, of the message differentially affects comprehension of data link or auditory messages. Incomplete messages are likely to invite incorrect inferences on the part of the pilot, or ATC. Our question is whether this situation is more likely when the mode of communication is textual or verbal.

The majority of the research on comprehension has been conducted in the written domain, and regards comprehension of textually presented passages. One of the most important factors that impacts comprehension is the coherence of the text. Coherence refers to the degree to which the text is conceptually explicit. When a text has many conceptual gaps, it is considered less coherent, and it is more difficult for the reader to understand. This inhibitory effect of coherence, however, depends on the reader's background knowledge. Reader's with greater expertise and prior knowledge are less affected by text coherence, and have even been shown to better understand low-coherence text (McNamara, Kintsch, Songer, & Kintsch, 1996). This leads to the prediction that less coherent texts may be optimal for pilots, who are high-knowledge within their domain.

However, the effects of coherence have not been studied with passages that are presented in the auditory modality. Hence, we can not predict based on previous results the relative differences in comprehension as a function of whether the information is verbally or textually presented. The effects of coherence have also not been examined for information that presents procedural instructions such as ATC messages. Coherence has been shown to have a greater effect on readers' mental model of textually presented information (e.g., McNamara et al., 1996). According to theories of comprehension (e.g., Kintsch, 1988), the mental model benefits from integrating prior knowledge with textual information. Therefore, coherence would be expected to have a large impact on comprehension of procedural information. Hence, one purpose of this project is to examine whether effects of text coherence depend on the mode of presentation and the type of information conveyed.

Coherence in data-link messages occurs at two levels. The first level regards whether the word is completely spelled out or abbreviated. For example, rather than spelling out the word *altitude*, it would be abbreviated as *ALT*. The second level regards whether the ideas are explicitly and coherently conveyed. For example, a less coherent version of the message 'Turn right with a heading of three two zero" would be "Right, three two zero". These two levels of coherence can vary concurrently. Hence, we will compare auditory and textual presentation of data-link messages that vary in coherence on two levels, the word and the idea. At the word level, words will be presented either intact (turn right) or abbreviated (trn R). At the sentence level, the messages will include all of the necessary words to form complete and coherent sentences. These two variables will be varied in a factorial design, resulting in four conditions of varying coherence. During the first phase of our project, we will conduct exploratory research to ascertain the actual format and content of ATC messages such that the content of our stimuli is as realistic as possible.

General Methodology

Subjects will be trained to 'fly' in a Microsoft Flight Simulator. Subjects will only be trained to fly in mid-flight and will not be trained to take off or land. Training will be administered with either visual or auditory display of messages. After reaching criterion for operating the flight simulator and for having memorized the abbreviations, the subjects will then be administered 8 tasks, 2 in each of the four levels of coherence. Messages will be delivered either auditorily or textually on a simulated data-link display. Performance will be assessed in terms of performance accuracy, performance reaction time, and message recall.

Subsequent experiments using this paradigm will address issues of message length, urgency, and expectancy. The specific methodology of these experiments, however, will depend on the results of our initial investigations.

Potential contribution

The results of these experiments will provide valuable information concerning comprehension in the ATC environment. These studies will specifically indicate whether coherence at either the word or sentential level interacts with the modality of presentation. These results will provide guidance concerning the importance of message coherence in data link as compared to auditory presentation of information. Furthermore, we will determine if these factors interact with variables such as message length, urgency, and expectancy.

Workload

To date, little effort has been aimed at understanding the effects of workload on the differences between text and speech communications. In one experiment, Mackintos, Lozito, McGann, and Logsdon (1999) examined the effects of "distractions" on message access times. These investigators found that when individuals were preoccupied with another activity at the time that the data-linked messages arrived, the mean time to access the message increased by about 10 seconds. Mackintos and her colleagues noted that an additional delay of 10 seconds could have serious consequences for flight crew performance. However, Mackintos and her colleagues did not perform any systematic analysis on the nature of the distractions in their study. Given the magnitude of the delay observed in their study, it seems a more comprehensive examination of workload is warranted.

Therefore, the third issue addressed by this project regards the effects of workload on performance in the ATC environment. The experimental paradigm employed will be the same as that described within the section of *Coherence*. All of the variables manipulated within that paradigm will be studied under low workload (single task) and high workload (multiple task) conditions. Under low workload conditions, the variables identified above will be studied in isolation (as described earlier). Under high workload conditions, the participants will perform the same data-link activities along with the Multi-attribute Task (MAT) battery (Comstock & Arnegard, 1992) on a separate computer. The MAT battery contains several tasks that represent the types of activities typically performed by pilots. These include a psychomotor tracking task, a monitoring task, and a resource management task. Under high workload conditions, the systematic effects of different levels of workload can be examined by adding tasks to be performed simultaneously. In addition, unexpected events can be programmed into the task and their effects on message access times and performance accuracy can be examined. It is expected that differences between the speech and text-based formats will be exacerbated under higher levels of workload. Further, the introduction of unpredictable events that require immediate action will lead to even longer message access times and generate a greater numbers of errors.

General Methodology

The experiments to address the issue of workload will be conducted under low workload, moderate workload, high-workload/predictable, and high-workload/unpredictable conditions.

The data for the low workload conditions will be obtained from the baseline experiments described in the section under *Coherence*. Moderate workload will involve performing the data-link activities simultaneously with the monitoring task. High workload will involve data-link activities performed simultaneously with the monitoring, tracking, and resource management tasks. In the high-workload/unpredictable condition, the effects of unexpected failures in the resource management task will also be examined.

In addition, participants will be asked to complete the NASA Task Load Index (TLX; Hart & Staveland, 1988). This instrument is a measure of subjective workload and ratings on the TLX will be used to corroborate workload effects as observed in performance.

Potential contribution

The issue of workload is germane to aviation. Hence, we believe that these experiments will provide critical information concerning the effect of workload on the comprehension of ATC messages and the successful completion of aviation-related tasks. A more complete understanding of how the complex interplay of variables in the ATC environment depends on workload will provide a more realistic set of guidelines for the format and content of ATC messages.

Facilities and Equipment

The necessary facilities including laboratory and office space will be provided by Old Dominion University. As reflected in the expected budget, we will need 2 computers that will be used to run the proposed experiments.

Timeline

RESEARCH AREA	Year 1	Year 2	Year 3
Working Memory Interference			
Experiments 1A and 1B	**X**		
Experiments 2A and 2B	**X**	**X**	
Experiments 3A and 3B		**X**	**X**
Message Coherence			
Task preparation (computer programming)	**X**		
Stimuli Development	**X**		
Experiments to address issues of coherence		**X**	**X**
Follow-up experiments to address issues of message length, urgency, and expectancy			**X**
Workload			
Task preparation		**X**	
Experiments		**X**	**X**

Estimated Budget

Salaries and Wages		**3-Year Total**
Danielle S. McNamara (PI)		
Academic Release (6.75 months, 25% per year)		23,000
Summer (3 months)		20,000
Mark Scerbo (Co-PI)		
Academic Release (6.75 months,, 25% per year)		26,000
Summer (3 months)		23,000
Postdoctoral Research Assistant		75,000
Salary represents 3/4 time research position for 3 years; Remainder of salary will be covered by psychology department with teaching responsibilities of one course per semester.		
Graduate Research Assistant		36,000
Computer Programmer		15,000
Fringe Benefits		20,000
Supplies		2,000
Equipment		4,000
Travel		10,000
	Subtotal	254,000
Indirect Costs		95,000
	Total	**349,000**

References

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