

INTERFERENCE EFFECTS ON THE RECALL OF WORDS HEARD AND READ: CONSIDERATIONS FOR ATC COMMUNICATION

Matthew R. Risser¹, Danielle S. McNamara¹, Carryl L. Baldwin¹,
Mark W. Scerbo¹, Immanuel Barshi²

¹Department of Psychology, Old Dominion University, Norfolk, VA

²NASA Ames Research Center, Moffet Field, CA

Two experiments were conducted to investigate the effects of interference on memory for words that were either read or heard. Interference tasks required either visual, verbal, or central executive (CE) working memory resources. Experiment 1 examined effects of simultaneous interference, whereas Experiment 2 examined the effects of posttask (subsequent) interference. When interference occurred simultaneously with word presentation, the verbal and CE interference tasks were most disruptive, regardless of whether the words were read or heard. Furthermore, hearing words facilitated recall in comparison to reading words regardless of interference source. When the interference task followed word presentation, CE interference again was the most disruptive. However, the effects of the visual and verbal interference tasks were equivalent. These results are discussed with respect to communication mode in ATC messages to pilots (i.e., textual data-link messages vs. voice transmissions).

INTRODUCTION

In today's flight environments, communication between the Air Traffic Controller (ATC) and the flight crew is usually conducted via voice transmission. In that environment, pilots are often required to perform multiple tasks that require competing attentional demands. Human performance limitations can affect various stages of cognitive processes in aviation such as the transmission, reception, comprehension, and confirmation of information. To relieve some of the cognitive overload, data-link was developed. Data-link aircraft communication is a technology that employs text messaging between ATC and the flight crew.

Although data-link was expected to reduce ATC and flight crew errors, this has not always been the case (Dunbar, McGann, Mackintosh, & Lozito, 2001; Issac & Ruitenbergh, 1999; Kerns, 1999; McGann, Morrow, Rodvold, & Mackintosh, 1998). However, errors resulting from the use of data-link are of a seemingly different nature than those associated with voice communication. The purpose of the present research was to investigate this issue by examining the effects of different types of interference on memory for auditorily and textually transmitted information.

As a framework, we turned to Baddeley and Hitch's (1974) memory model, which proposes three components of working memory: a central executive (CE) responsible for reasoning processes, a visuo-spatial sketchpad for visual and spatial processing, and an articulatory loop for phonological (e.g., verbal)

processing. According to this model, the CE relies on the verbal and visual processing mechanisms, whereas the verbal and visual components are relatively independent of each other. Wickens (1984) similarly proposes that separate resources are available with respect to the information-processing channel (auditory or visual), type of code (spatial or verbal), and processing stages. Thus, Wickens' multiple resource theory makes more specific distinctions between the types of resource pools than does Baddeley's working memory model. Nevertheless, both theories predict that tasks that draw on the same pool of resources will result in greater interference and performance decrements than do tasks that draw on separate resources.

During flight, pilots are engaged in numerous visual tasks such as monitoring instruments and flight path data. Data-link introduces an additional visual processing task to the already visually rich environment. This situation creates the potential for interference between tasks that draw on the same pool of visual resources, whereas voice communication draws on auditory resources, which are not as heavily taxed on the flight deck. Hence, our goal is to determine whether information that is read (as are data-link messages) is more susceptible to interference from competing visual tasks than information that is heard (as are voice transmissions).

Our approach in the present research was to control the experimental environment as much as possible before extending our research to tasks with greater external validity with respect to the piloting domain.

Hence, the experimental paradigm that we adopted is notably simplistic in comparison to the complexity of actual aviation environments. Specifically, we used a simple word recall paradigm. To simulate data-link messaging, participants read 15 words on a computer screen. To simulate radio transmission, participants heard the same words. Thus, to-be-remembered words were presented in either a visual or auditory format. To examine the potential for processing interference, word presentation was combined with four types of interference tasks that drew upon central executive (CE task), verbal (VB task), visual (VS task), and no (control task) resources. Moreover, because interference in the cockpit may be either concurrent or subsequent to an ATC message, we investigated both concurrent interference (Experiment 1) and subsequent interference (Experiment 2).

We expected that when participants read the words, recall would suffer more in the context of the VS task than of the VB task, and that conversely, when participants heard the words, recall would suffer more in the context of the VB than of the VS task. The CE task was expected to be equally disruptive to recall for words that were read or heard. We expected similar patterns of results under both concurrent and subsequent interference, but that recall would suffer to a greater degree under concurrent than under subsequent interference.

METHOD

Participants

Experiments 1 and 2 each included 40 college students who participated for credit in a psychology course. All had normal or corrected-to-normal vision and no reported auditory deficits. Data from one participant in Experiment 1 and two participants from Experiment 2 were unreliable and they were replaced. All participants were native speakers of English.

Design

Word presentation modality (reading, hearing) was a between-subjects factor. Interference task (control, VS, VB, and CE) and experimental block (first, second) were within-subjects factors. The dependent measures were the number of words correctly recalled for the primary task and the number of hits, misses, and false alarms in the VB and VS interference tasks.

Participants were assigned to either reading or hearing presentation condition on an alternating basis. All participants performed three blocks of four trials each, in which the four interference task conditions were presented in a counterbalanced order. The first block of trials was considered practice and the remaining two

blocks comprised the experimental trials used in the analysis.

Word Presentation Modality

The word lists were comprised of 180 relatively frequent nouns that contained no more than two syllables. Each of 12 trials consisted of a list of 15 words (counterbalanced for word frequency, length, and concreteness). Participants recalled as many words as possible in any order at the end of each trial. In the reading condition, words were presented one at a time on a computer screen for approximately 500 ms with a 1000 ms ISI. In the hearing condition, words were presented one at a time via computer speakers with a mean duration of 500 ms and a 1000 ms ISI. A male native speaker of English digitally recorded each word. All words were presented at a normal conversational level of approximately 60 dB.

Interference Tasks

VS Task. The VS task consisted of visual presentation of 15 letters. Participants responded by pressing the space bar if the visually presented letter had a curve. For example, the letters C, D, or U required a response, whereas Z, T, or V did not.

VB Task. The VB task employed the same visual presentation of 15 letters as the VS task, except that responses (in the form of space-bar presses) were required if the letter contained an /ee/ sound. For example, the letters T, V, and D required a response, whereas R, L, or W did not. Participants were not to speak the letters aloud but were expected to subvocalize the letter.

CE Task. The CE task required participants to randomly generate and speak out loud random letters. Participants were instructed not to use any type of strategy.

Control. In the control condition, there was no interference and participants recalled the words immediately after list presentation.

Experiment 1

In the first experiment, the words and the interference tasks were presented concurrently. In the reading condition, each of the 15 letters (for VB and VS interference tasks) was presented directly below the word. In the hearing condition, each letter was presented on the computer screen simultaneously with word presentation. Following each trial, participants recalled the words.

RESULTS

A repeated measures GLM (using Greenhouse-Geisser degrees of freedom) was performed on the number of words correctly recalled. A Student Newman Keuls post-hoc comparison was used to analyze significant interactions.

There was a significant effect of interference task, $F(3,114)=116.62, p<.05$. A post-hoc analysis indicated that recall was greater for the control task ($M=6.88$) than the VB ($M=3.23$), VS ($M=4.43$), and CE ($M=2.80$) interference tasks, and that the VB and VS, and the VS and CE tasks were significantly different.

In addition, there was a significant interference task by presentation condition interaction, $F(3,114)=5.48, p<.05$ (see Figure 1). A post-hoc analysis indicated that in both presentation modality conditions, all means were statistically different from one another except for the CE and VB interference tasks, which did not differ. For the control task, more words were recalled in the reading condition than in the hearing condition. Conversely, more words were recalled in the hearing condition than in the reading condition in the context of both VB and VS interference tasks.

Hits, misses, and false alarm responses to the VB and VS interference tasks were also analyzed. There were no reliable differences for the number of hits or misses between the VB and VS tasks. However, there were significantly more false alarms, $F(1,38)=21.96, p<.05$, in the VB task ($M=1.16$) than in the VS task ($M=0.45$).

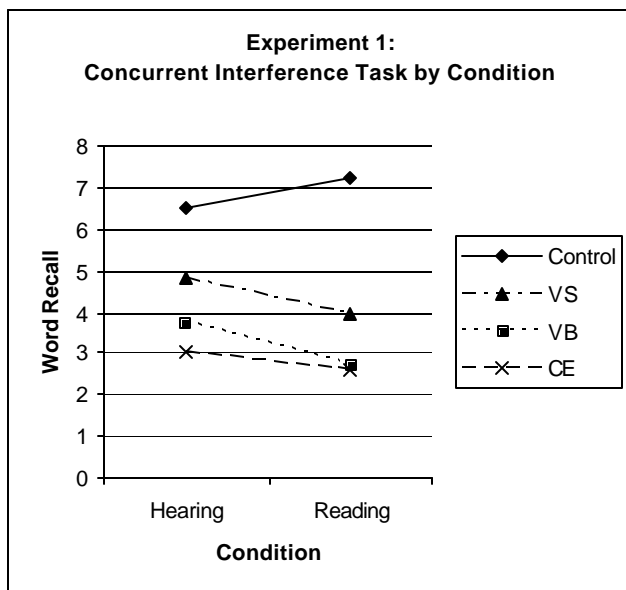


Figure 1. Number of words recalled in Experiment 1 as a function of word presentation condition and interference task.

Experiment 2

The procedure for Experiment 2 was the same as Experiment 1, with one exception. In Experiment 2, the interference task followed the presentation of all the words in the trial. For all experimental conditions, the participants performed the interference task for 20 seconds before being asked to recall the list of words.

The results revealed a significant effect of interference task, $F(3,114)=24.94, p<.05$. A post-hoc analysis demonstrated that more words were recalled in the control task ($M=6.74$), than in the VB ($M=5.73$), VS ($M=5.66$), and CE ($M=4.25$) interference tasks. In addition, significantly fewer words were recalled in the CE interference task than in the control, VB, and VS interference tasks. The interaction of presentation condition and interference task was not reliable (see Figure 2).

Similar to Experiment 1, there were no significant differences for the hits and misses in the VS and VB interference tasks. There were significantly more false alarms, $F(1,38)=12.66, p<.05$, in the VB task ($M=0.65$) than in the VS task ($M=0.24$).

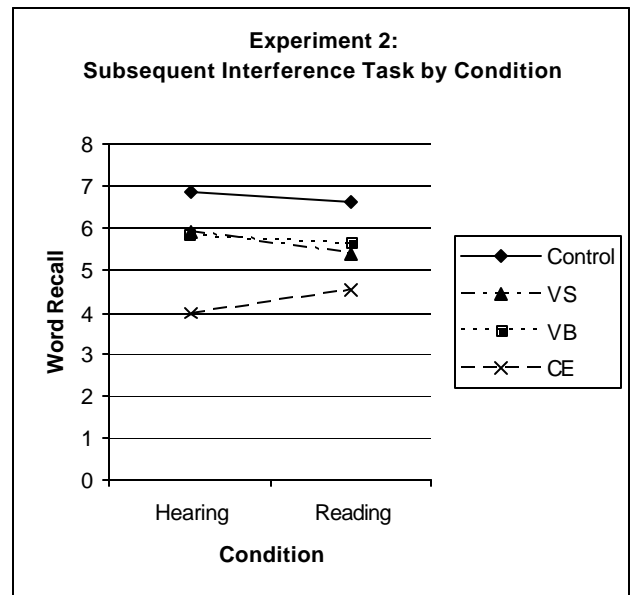


Figure 2. Number of words recalled in Experiment 2 as a function of word presentation condition and interference task.

One of our questions regarded differences between concurrent and subsequent interference. Therefore, we conducted a post-hoc comparison between the two experiments. One important caveat to this comparison is that participants were not randomly assigned to experiment – the experiments were run separately. Nevertheless, the experimental conditions were

identical. As expected, the analysis including experiment as a between-subjects factor indicated that there were significantly more words recalled, $F(1,76)=28.11, p<.05$, with subsequent interference (Exp. 2; $M=5.59$) than with concurrent interference (Exp. 1; $M=4.33$). In addition, there was a significant experiment by interference task interaction, $F(1,228)=16.65, p<.05$, reflecting a greater difference in Experiment 1, $t(39)=12.46, p<.05$, between the control ($M=6.88$) and interference ($M=3.48$; t) conditions than in Experiment 2, $t(39)=5.54, p<.05$ (control $M=6.74$; interference $M=5.21$). This result supports the conclusion that there is a greater effect of concurrent than subsequent interference. However, these results did not depend on whether the information was read or heard.

DISCUSSION

The purpose of the current investigation was to examine the effect of different forms of interference on memory for words that are read or heard. As one might expect, participants recalled more words when there was no interference than when there was either concurrent or subsequent interference. Furthermore, participants were affected more by concurrent than by subsequent interference. Also, not surprisingly, the CE interference task resulted in the greatest recall decrements in both experiments. The latter result indicates that interference requiring reasoning, judgment, or decision making will be disruptive to memory regardless of whether it occurs during or after encoding. Notably, CE tasks may be more relevant to the cockpit domain where judgments and decisions are often necessary before performing an action. In terms of ATC communication, this result suggests that pilots who engage in extraneous higher-order thinking during or following ATC message reception may have more difficulty recalling portions of the message.

Our main focus here, however, was on the differences between verbal and visual interference as a function of whether the information was heard or read. We expected a cross-modal interaction. Experiment 1 showed a significant interaction of interference task by presentation condition, but not in the predicted direction. Instead, we found that the VS and VB interference tasks both disrupted recall more when the words were read than when they were heard. The VS task required processing in terms of visual code (i.e., the curvature of the letter), whereas the VB task required processing in terms of a verbal code (i.e., the sound of the letter). However, both tasks were presented visually and thus utilized the visual processing channel. Given Wickens' (1984) theory of multiple resources, this interaction

suggests that processing information visually (regardless of the code) will be more disruptive to reading than to hearing information. Hence, ATC messages presented via data-link as opposed to voice communication may be more susceptible to competing tasks in the visually rich cockpit environment.

According to the Baddeley and Hitch (1974) and Wickens (1984) models, the absence of an interaction between the VS and VB interference tasks and word presentation modality suggests that reading and hearing words involve different pools of resources. The greater interference from the VB task supports that conclusion. Alternatively, the VB task is somewhat different than the VS task because it requires both visual and verbal processing – participants read the letters *and* made a phonological judgment. Thus, the VB task requires one to process the letter visually, and transform the visual code into a verbal code. This extra processing may have resulted in the greater memory deficits produced with the VB interference task, both in terms of false alarms and word recall (i.e., in Experiment 1).

Furthermore, in both experiments we found that the VB interference task produced more false alarms (i.e., responding to letters without an /ee/ sound) than the VS interference task (i.e., responding to letters without curves). The VB interference task was also more disruptive to word recall than the VS interference task in Experiment 1. One interpretation of this result is that the phonological processing required by both the VB interference task and the word processing task competed for resources, regardless of whether the words were heard or read. This competition inhibited word recall when the tasks were performed simultaneously in Experiment 1, and resulted in greater false alarms when the tasks were performed simultaneously and consecutively (perhaps competing with word rehearsal). These results suggest that interference involving phonological processing will be particularly disruptive to other verbal tasks regardless of the processing channel. Thus, verbal interference (such as conversation in the cockpit or reading alphanumeric displays) during an ATC message is likely to be more disruptive than the processing of purely graphically displayed information.

Two additional experiments using a similar paradigm are currently being conducted to explore the latter interpretation of our results. These experiments utilize the same word presentation manipulation (hearing versus reading words) in combination with the same CE, VB, and VS interference tasks with two notable exceptions. In the new set of ongoing experiments, the VB task is presented auditorily rather than visually and the interference tasks are presented immediately after the word presentation rather than simultaneously. This modification equates the VB and VS tasks in terms of

total processing requirements, while still tapping into different resource pools. Preliminary results from these experiments are consistent with the results of the two experiments reported here, demonstrating a similar interference task effect. However, there also appears to be a presentation modality effect such that performance in the VB interference task suffers more when words are presented auditorily than when they are presented visually. This result suggests that when words are heard, performance on the recall task can be maintained at the expense of performance on the VB interference task. These preliminary findings suggest that presenting the VB interference task visually, as in the experiments described here, changed the nature of the task to one that required fewer phonological resources. This is because responding to the VB interference task requires verbal/phonological processes and resources. However, in the new experiments, verbal/phonological processes and resources are also required for *encoding* the stimuli, whereas in the experiments described here such encoding required visual resources rather than verbal. Thus, when the task is presented auditorily (as in the new ongoing experiments) there may be increased competition for phonological resources. However, the effects of this competition seem to emerge for performance on the interference task, rather than on word recall.

The experiments presented here were designed with the intention to create a theoretical foundation for examining verbal code processing and interference as a function of presentation modality (auditory vs. visual). Ultimately, this theoretical framework will be reexamined in higher fidelity experimental paradigms using ATC-like communication (both voice and data-link).

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