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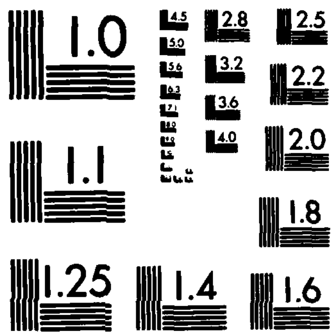
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THE USE OF INTERACTIVE VOICE SYSTEMS TO IMPROVE MULTIPLE-TASK PERFORMANCE

Final Technical Report
Contract # N00014-82-L-0179

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This report summarizes six major experiments conducted during three funding periods on the contract entitled "The Use of Interactive Voice Systems to Improve Multiple-Task Performance." All six of these experiments examined the effects of voice generation and recognition systems on the performance of task combinations consisting of either two discrete tasks or a discrete task and a tracking task. This contract also supported work on three other related topics. These topics are described and the products of these lines of investigation are discussed. A list of all the journal articles, technical reports, scientific papers, and theses supported by this contract is given at the end of the report. This list also contains all of the software and experimental tasks developed under this contract.

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Introduction

This report describes the activities completed during three funding periods on Contract #N00014-82-C-0179, "The Use of Interactive Voice Systems to Improve Multiple-Task Performance." As the title implies, the primary purpose of this contract was to examine the effect of voice generation and recognition systems on dual-task performance although three other research efforts on complementary topics also were investigated.

This report is divided into four sections. The first section provides background information for the first experiments conducted under this contract. The second section describes each of the six experiments examining the effect of voice generation and recognition systems on dual-task performance and summarizes their results. The third section briefly discusses three other research efforts performed on this contract in support of current activities at the Naval Biodynamics Laboratory and the Naval Aerospace Medical Research Laboratory. The last section of this reports lists the products of the contract.

Background

Originally, this contract was to examine the effects of voice generation and recognition systems on the dual-task performance of a tracking task and a discrete information processing task. However, by the time the contract was awarded, several other investigators had published experiments on this topic. The P.I. and the contract monitor decided, therefore, to change the topic slightly to prevent duplication of effort.

Consequently, the first experiments conducted under this contract examined the effect of voice generation and recognition systems on the performance of a discrete task combination.

The P.I. noticed that there were no data in the open literature from task combinations consisting of a verbal short-term memory task and a spatial short-term memory task. The lack of such data was surprising; this combination appears to be important in flying, particularly in the approach phase of instrument landings. During instrument approaches the pilot must remember the flight path to be executed while also remembering specific traffic instructions and other restrictions. Thus, the pilot seems to use both the verbal and spatial short-term memory systems concurrently during these approaches. Because there were no data from task combinations using both of these memory systems, the P.I. decided to examine this type of combination in the first experiments.

Additionally, the P.I. decided to investigate the role of asymmetric transfer in studies of interactive voice systems. Asymmetric transfer occurs in within-subject (repeated measures) experiments when transfer from one level to another of a within-subject factor is qualitatively different from transfer in the opposite direction. Its effects are frequently so large that statistical analyses performed on affected data may give spurious results. Before the first experiment began, Poulton (1982) published an article concerned with asymmetric transfer in dual-task experiments. Although Poulton gave few guidelines for predicting the occurrence of asymmetric transfer, it appeared that asymmetric transfer could influence experiments examining voice generation and recognition systems in dual-task situations.

Research Examining the Effects of Voice Generation and Recognition Systems on Dual-Task Performance

Because the purpose of this contract was to examine the effect of voice generation and recognition systems on dual-task performance, no single-task analyses are reported for any of the six experiments. Effects involving practice are also not reported because they were predictable and in most cases, uninteresting. Only significant ($p < .05$) results are described.

Experiment 1. The purpose of Experiment 1 (Damos, 1985) was to examine the effect of a voice generation and a voice recognition system on the performance of a discrete task combination consisting of a verbal short-term memory task and a spatial short-term memory task. The spatial short-term memory task was developed specifically for this contract and was based on earlier work by Phillips (1974). For this task 5 x 5 matrix grids were presented sequentially to the subject. Each matrix had five illuminated cells, which were selected at random. The subject's task was to determine if the current matrix was identical to the preceding matrix rotated 90 degrees to the right or left. The subject responded either "same" if this was the case or "different" if the current matrix was not a rotation of the preceding one. The verbal short-term memory task used randomly selected digits between one and four. The digits were presented sequentially and the subject was required to respond to the digit preceding the one currently displayed.

A four-factor, mixed-model experimental design was used.

Trials and the stimulus mode of the verbal task (visual versus auditory) were within-subject factors. Order of the stimulus mode (visual first versus auditory first) was a between-subjects factor. Response mode of the verbal task (manual versus speech) also was a between-subjects factor. An Auricle 1--a speaker-dependent, isolated word recognition system--was used to identify vocal responses; a Micromouth voice generation system presented auditory stimuli to the subject.

The results of the analysis performed on the dual-task verbal memory data showed an interaction involving the stimulus mode and the response mode. This interaction occurred because the auditory stimuli resulted in better performance than visual stimuli when subjects responded to the verbal memory task manually rather than vocally. No corresponding difference occurred when speech responses were used.

There was also a significant stimulus mode by order interaction. This interaction indicates that asymmetric transfer occurred between the stimulus modes; asymmetric transfer is revealed either by a main effect of order or by an interaction between order and the within-subject factor (stimulus mode in this case). Currently, there is no way to adjust for the bias introduced by asymmetric transfer. To obtain an unbiased estimate of the effect of the within-subject factor on performance, all of the data affected by asymmetric transfer must be discarded and the analyses recalculated. This implies that all of the data obtained under the second stimulus mode condition had to be excluded from the analysis. When this was done, the resulting analysis showed essentially the same results as the first one.

The analysis performed on the dual-task data from the spatial memory task, the matrix task, showed a main effect of stimulus mode indicating that subjects performed the matrix task better when the stimuli for the verbal task were presented auditorily rather than visually. There was also a significant stimulus mode by order interaction, indicating the presence of asymmetric transfer. The analysis performed only on the data from the first stimulus mode condition showed no significant effects.

Two results from this experiment are of major importance. First, none of the dual-task analyses showed any advantage for the use of the voice recognition system. This is in marked contrast to almost all of the research published in the open literature (Harris, North, and Owens, 1977; Harris, Owens, and North, 1978; North, Mountford, Edman, and Guenther, 1980; Skriver, 1979; Wickens, 1980; Wickens, Sandry, and Vidulich, 1983). Second, there was strong asymmetric transfer between stimulus modes that biased the initial analyses. The presence of asymmetric transfer was somewhat surprising; it had not been identified in any comparable earlier research. It was decided, therefore, to perform a second experiment that would allow asymmetric transfer between response modes to be identified.

Experiment 2. The verbal short-term memory task used in Experiment 1 was too easy for college students. Therefore, a mental arithmetic task, the running difference task, was used as the verbal short-term memory task in this and all of the following experiments. In this task randomly selected digits between 0 and 8 were presented sequentially to the subjects. The subjects responded either vocally or manually with the absolute difference between the most recently displayed digit and the preceding digit. Stimuli were presented either visually or auditorily using a Digitalker, a new voice generation system that was used in all subsequent experiments.

This experiment (Damos and Lyall, 1986) used a four-factor, mixed-model design. Trials and response mode (manual versus speech) were within-subject factors. Order of response mode (manual first versus speech first) and stimulus mode (visual versus auditory) of the running difference task were between-subject factors.

The analyses performed on the running difference task showed main effects of stimulus mode, reflecting more accurate performance with auditory stimuli than visual, and response mode, indicating more accurate performance with manual responses than speech. There was also a response mode by order interaction, which signaled the presence of asymmetric transfer. To correct for asymmetric transfer, the data from the second response mode condition were discarded for all subjects and the analysis was recalculated. Only the main effect of stimulus mode remained significant.

The analysis performed on the correct reaction times of the matrix task showed a main effect of response mode favoring speech over manual responses. The same analysis performed on the percentage correct showed a main effect of response mode. This effect favored the manual mode over the speech mode. Both analyses showed evidence of asymmetric transfer. When the asymmetric transfer was eliminated, there were no significant main effects in either analysis.

The results of Experiment 2 were similar in several ways to those of Experiment 1. Experiment 2 showed evidence of asymmetric transfer between levels of the within-subject factor as did Experiment 1. In Experiment 2, of course, this transfer was between response modes rather than between stimulus modes. Experiments 1 and 2 both showed that dual-task performance improved when stimuli for the verbal memory task were presented auditorily rather than visually. Finally, although there were three significant main effects of response mode in Experiment 2, two of these favored manual responses over speech. When the effects of asymmetric transfer were eliminated, all three of these main effects failed to reach significance although this was probably the result of low statistical power. Thus, this experiment provided only very limited evidence that voice recognition systems can be used to improve dual-task performance.

The results of Experiments 1 and 2 differ from the results of the vast majority of earlier research examining the effects of voice generation and recognition systems on dual-task performance. This difference might have occurred because asymmetric transfer biased the results of Experiments 1 and 2 in some manner that was not adequately taken into account. Therefore, the P.I. decided to repeat Experiment 2 using a strictly between-subjects design to preclude any bias from asymmetric transfer.

Experiment 3. Only two changes were made from Experiment 2 to Experiment 3 (Damos, in press). First, a Votan 5000--a speaker-dependent, isolated word recognition system--was used instead of the Auricle 1. Second, a three-factor, mixed-model design was used. Response mode (manual versus speech) and stimulus mode (visual versus auditory) were between-subjects factors. Trials was a within-subject factor.

The analysis performed on the dual-task correct reaction times from the matrix task showed no significant effects. The corresponding analysis of the percentage correct showed only a main effect favoring the use of auditory stimuli over visual stimuli. The multivariate analysis performed on the percentage correct and the correct reaction times from the running difference task showed significantly more accurate but slower performance with auditory stimuli as compared to visual stimuli.

The results of this experiment, like those of Experiments 1 and 2, showed no advantage for speech over manual responses. Again, these results conflict with those of earlier studies that demonstrated a distinct advantage for the use of a voice recognition system. Two explanations were offered for this conflict. First, the use of a voice recognition system improves dual-task performance only when there is a high demand on the subject's response resources. Because Experiments 1, 2, and 3 used discrete task combinations, the load on the subject's response resources was low compared to that experienced by subjects in earlier studies; all of the earlier experiments used a tracking-discrete task combination. Second, undetected asymmetric transfer biased the results of the earlier studies in favor of voice recognition systems.

To decide between these two explanations, subjects in Experiment 4 performed a tracking-discrete task combination that was very similar to that used in earlier studies. Experiment 4 was designed to identify asymmetric transfer only between response modes of the discrete task; the stimulus mode of the discrete task was not manipulated.

Experiment 4. Subjects in this study (Lyall, under review) performed a one-dimensional compensatory tracking task using a control stick mounted on the left side of the experimental chair. The subjects attempted to center a cursor in the tracking display by using left-right movements of the control stick. The running difference task was used as the discrete task. Only auditory stimuli were used for this task.

This study used a three-factor, mixed-model design. Response mode (speech versus manual) and trials were within-subject factors. Order of response mode (manual first versus speech first) was a between-subjects factor.

The analysis of the tracking data showed a main effect of response mode favoring the use of speech for the running difference task. However, asymmetric transfer was present. When the asymmetric transfer was eliminated, the advantage attributed to speech was no longer significant. The multivariate analysis performed on the running difference data showed significantly faster and more accurate performance with manual responses as compared to speech. Asymmetric transfer was also present in these data with the bias favoring the speech response mode.

The results of Experiment 4 are in direct conflict with most of the earlier research that used a tracking-running difference combination (Harris, Owens, and North, 1977; Harris, North, Owens, 1978; Wickens, 1980; Wickens, Sandry, and Vidulich, 1983); almost all of these studies found better performance on both the tracking task and the running difference task when the subjects responded vocally rather than manually to the running difference task. The major implication of Experiment 4 is that the results of the earlier studies may have been biased in favor of the speech response mode by undetected asymmetric transfer.

Because of the seriousness of this implication, the P.I. decided to "replicate" Experiment 4 using a strictly between-subjects design. As noted earlier, the use of such a design completely eliminates any possibility of asymmetric transfer. The stimulus mode of the running difference task was included as a variable in Experiment 5 to detect any interaction between the stimulus mode and the response mode for the tracking-running difference combination. No other changes were made in the task, apparatus, or procedure.

Experiment 5. This experiment (Damos, in press) used a three-factor, mixed-model design. Response mode (vocal versus manual) and stimulus mode (auditory versus visual) were between-subjects factors. Trials was a within-subject factor.

The analysis of the tracking data showed no significant effects. The multivariate analysis performed on the running difference data showed a main effect of stimulus mode, indicating more accurate performance with auditory stimuli.

Thus, the results of Experiment 5 corroborate those of

Experiment 4; the use of a voice recognition system does not result in significantly better performance on either the tracking task or the running difference task than the use of a keypad. Additionally, this experiment provides more evidence that the use of a voice generation system improves performance in a tracking-running difference task combination.

Conclusions From Experiments 1-5. Three major conclusions can be drawn from the results of the five experiments described above. First, under dual-task conditions asymmetric transfer occurs between stimulus modes and response modes of verbal short-term memory tasks. The size of the asymmetric transfer is sufficient to cause spurious statistical effects that generally favor the use of voice technology.

Second, the use of voice recognition systems in dual-task situations does not significantly improve performance over the levels obtained using conventional manual devices. This observation must be qualified by noting that all five of the experiments described above used a speaker-dependent, isolated word recognition system. The results of these experiments might have been different if a speaker-dependent, connected word system with a very short template-matching time had been used.

Third, the use of a voice generation system can improve dual-task performance significantly. This result is particularly encouraging because the voice generation systems used in these experiments were inexpensive devices. In addition these systems resulted in better dual-task performance in all three of the task combinations used in the five experiments. Thus, these systems appear to improve performance when at least one of the tasks requires verbal short-term memory.

Experiment 6. The sixth major experiment (Damos, under review) performed under this contract examined a different problem than the preceding five studies. Skriver (1979) found that task difficulty had little effect on vocal correct reaction times but a large effort on manual correct reaction times. These results support the general assumption that voice technology can be used to reduce workload. However, like almost all of the earlier work, Skriver used a within-subject design. Thus, his results may have been biased in favor of the speech response mode by asymmetric transfer.

Experiment 6 examined dual-task performance as a function of difficulty, stimulus mode, and response mode. The combination consisted of a spatial task (the maze task described in the following section) and the running difference task. A four-factor, mixed-model design was used. The difficulty of the maze task (high complexity versus low complexity), the response mode of the running difference task (vocal versus manual), and the stimulus mode of the running difference task (visual versus auditory) were between-subjects factors. Trials was a within-subject factor.

It should be noted that this experiment differed from Skriver's in several ways. First, the task combination was different. Skriver used a tracking-choice reaction time combination. Second, the stimulus mode of the verbal task was manipulated as an experimental factor; Skriver presented all of his stimuli visually. Third, response mode was a between-subjects factor, not a within-subject factor. Fourth, Skriver assumed that the speech response mode resulted in lower workload because performance was better with vocal than manual responses. However, he collected no data to support this assumption. Subjective estimates of workload were obtained in this experiment using a scale developed at NASA (Hauser, Childress, and Hart, 1982).

The dual-task data from the running difference task showed a main effect of complexity level with subjects in the high complexity groups performing more poorly than those in the low complexity groups. Stimulus mode was also significant, indicating that subjects who received auditory stimuli for the running difference task performed more accurately than those receiving visual stimuli. Finally, there was a significant complexity level by response mode interaction for percentage correct. This indicates that subjects were less accurate in the high complexity/speech response groups than in the low complexity/speech response groups. In contrast subjects in the high complexity/manual response groups were more accurate than those in the low complexity/manual response groups.

The solution times for the maze task were also adversely affected by high complexity level and the use of visual stimuli for the running difference task. Additionally, solution times were greater when subjects responded manually rather than vocally to the running difference task. There was also a complexity level by response mode interaction. This interaction indicated that there was a much greater performance difference between the low and high complexity/manual response groups than between the low and high/speech response groups.

The results of this experiment do not show a clear advantage for the use of a voice recognition system as task difficulty increases. Rather, the results indicate a different speed/accuracy trade-off for the manual and speech response groups. Subjects in the high complexity/manual response groups were more accurate on the running difference task but slower to solve mazes than those in the low complexity/manual response groups. In contrast subjects in the high complexity/speech response groups were considerably more inaccurate on the running difference task but only a little slower on the maze task than those in the low/complexity speech groups. It is obvious, however, that subjects prefer the voice recognition system to a keypad to perform this combination; an analysis of the workload scales revealed that subjects experienced lower physical effort, mental effort, and overall workload with vocal as compared to manual responses.

Other Research Efforts

Three other lines of research were conducted under this contract. The first involved the development of two new computerized spatial tasks. When this contract was begun (early 1982), there were relatively few computerized spatial tasks available as experimental tasks that had been carefully developed and thoroughly validated. It was necessary, therefore, to construct spatial tasks with the characteristics that met the requirements of Experiments 1 through 6.

The first task developed under this contract was the matrix task described earlier. The initial programming and testing of this task required approximately 8 months; task refinement required an additional 10 months. The software for this task was sent to the Naval Aerospace Medical Research Laboratory where it was incorporated in the aircrew selection battery under development (see Gibb and Damos, 1986). It has also been used in at least one major experiment at the Naval Aerospace Medical Research Laboratory.

The second task, the maze task, required approximately 1.5 years for the initial development and validation. Seven pretests exploring the characteristics of the task were conducted; five of these are reported in Damos and Lyall (1986). This task was used in Experiment 6 and the software was sent to the Naval Biodynamics Laboratory for use in the shipboard motion program. The software may also be sent to the Naval Aerospace Medical Research Laboratory in late 1986 for further validation.

The second line of research involved the examination of shipboard motion on single- and dual-task performance. Three tasks were sent to the Naval Biodynamics Laboratory for preliminary investigation in motion and no-motion conditions. However, because of problems with the shipboard motion simulator, no data were collected under motion conditions and it was not possible to examine dual-task performance under either the motion or the no-motion conditions before the end of this contract.

The third line of research, which was partially supported by this contract, concerned the development of a new technique for isolating timesharing skills and abilities. This research was conducted in collaboration with Dr. Alvah Bittner, Jr., a scientist from the Naval Biodynamics Laboratory. A technical report describing the technique was published through the Naval Biodynamics Laboratory (Bittner and Damos, 1986) and a journal article is currently under review at Human Factors.

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CONTRACT PRODUCTS

Papers Presented At Scientific Meetings

Damos, D.L. (1983, October). Improving dual-task performance using speech technology. Paper presented at the 27th Annual Meeting of the Human Factors Society, Norfolk, VA.

Damos, D.L. and Lyall, E.A. (1984, October). The effect of asymmetric transfer on dual-task assessment of voice technology. Paper presented at the 28th Annual Meeting of the Human Factors Society, San Antonio, TX. (Paper presented by Lyall).

Damos, D.L. (1985, April). The effect of using speech generation and recognition systems on the performance of discrete tasks. Paper presented at the Third Symposium on Aviation Psychology, Columbus, OH.

Damos, D.L. (1985, June). Effect of asymmetric transfer on research using speech generation and recognition systems. Paper presented at the Western European Association of Aviation Psychologists, Helsinki, Finland.

Damos, D.L. (1985, November). Evaluating the effects of voice generation and recognition systems in multi-task situations: Methodological problems. Paper presented at the IEEE Systems, Man and Cybernetics International Conference, Tucson, AZ.

Damos, D.L. (1986, April). The role of asymmetric transfer in the evaluation of voice generation and recognition systems. Invited paper presented at AGARD Aerospace Medical Panel Symposium on Information Management and Decision-Making in Advanced Airborne Weapons Systems, Toronto, Canada.

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Lyall, E.A. (under review). Asymmetric transfer and its origin in a continuous and discrete task combination. *Human Factors*.

Bittner, A.C., Jr., and Damos, D.L. (under review). Demonstration of a statistical method for isolating timesharing components. *Human Factors*.

Software

1. Matrix task -- This task was developed in the first two years of the contract. The software was sent to the Naval Aerospace Medical Research Laboratory, where it has been incorporated into the aircrew selection battery under development. It has been used in the Therapeutic Drugs in Aviation (61153N MR04101.03 0160) and Biomedical Effects of Chemical Agent Antidotes and Pretreatment Drugs (63764A 3M263764 B995 AB082) projects at the Naval Aviation Medical Research Laboratory. The matrix task also has been included in the Unified Tri-Services Cognitive Performance Assessment Battery.

2. Verbal short-term memory tasks -- The software for two verbal short-term memory tasks, the running difference task and the Hunt-Lansman memory task, was developed and sent to the Naval Biodynamics Laboratory for shipboard motion testing. Baseline data for these tasks have been collected.

3. Maze task -- Software for this task was developed during the last 1.5 years of this contract. The software and the IBM XT purchased on this contract have been sent to the Naval Biodynamics Laboratory for shipboard motion testing. The IBM XT and the software may be sent to the Naval Aerospace Medical Research Laboratory in November, 1986 for further testing.

4. Lawley's Chi-Square Test -- The original software for this test of differential stability was developed during the second funding period. This software was later modified as part of the P.I.'s 1985 Naval Aerospace Medical Research Laboratory IGPA and sent to the Naval Aerospace Medical Research Laboratory for use on several projects.

Technical Reports

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Thesis Supported

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