BIMODAL WORD PROCESSING: SPEED, ACCURACY, AND MEMORY

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Summary

A group of 20 experienced sonar operators (SO) was compared with a group of 20 non-operators (NO) on a computerized word decision task. The subjects had to respond quickly and accurately in determining whether a word/words presented visually and/or aurally (at the same time) was/were related to a given category (i.e., animals). Response speed, decision accuracy, and recall of words related and unrelated to the categories were recorded. Results indicated no group differences in any of the dependent measures, thus experience in a bimodal input situation did not provide sonar operators with a performance advantage on the experimental task. All 40 subjects performed faster and more accurately when the information was presented visually, and the words were related to a given category. Subjects performed about as quickly and accurately when the same word (related to the category) was presented concurrently in both modalities, however, recall of these words was significantly higher than all other conditions. Overall, the data are consistent with other studies which demonstrate no loss and some gain in the bimodal redundant (same word) condition. This study is one of the first to demonstrate an enhancement in higher level cognitive performance (such as memory recall) in a bimodal task.

Introduction

A growing body of literature suggests that in various detection and decision tasks that "redundant" relevant information in two modalities is as useful or more beneficial than either single input alone (Lewandowski & Kobus, 1989). Such results have been demonstrated using simple stimuli as lights and tones (Nickerson, 1973) as well as more complex stimuli as sonar signals (Kobus et al., 1986), letters (Miller, 1982), and words (Lewandowski, Hursh, & Kobus, 1985). A long-standing interest in the processing of dual signals has been evidenced by sonar operators and research scientists working with sonar systems. While sonar systems such as those used by the U.S. Navy have changed considerably over the years, modern systems continue to provide operators with concurrent visual and auditory information. At times that information may be simple or complex, contain alphanumeric symbols or not, and be redundant or conflictual. The ability to make cognitive decisions on the basis of incoming bimodal information under these various conditions warrants ongoing investigation. A simple question remains: "What is the best information delivery condition for the sonar operator?"

Research on bimodal processing on Navy sonar systems has consistently indicated a value in providing two inputs versus one to an operator (Kobus & Lewandowski, 1986; Lewandowski & Kobus, 1985). Yet, with ever-improving computer graphics, the visual component of the information delivered has been enhanced and complicated. It has been suggested that the enhanced visual displays may be best if operated in isolation, and that the auditory information may actually be deleterious to overall operator performance.

The question then becomes: "Does the auditory channel provide any useful information above and beyond the visual channel alone?" Thus far, research has suggested that redundant information, delivered concurrently in two channels, tends to have a positive effect on performance, a finding which has held across a range of context and stimulus types. For example, Lewandowski and Kobus (1985) found that target detection thresholds were reduced when an equivalent sonar target was concurrently presented in both the visual and auditory channels. Lewandowski, Hursh, and Kobus (1985) extended this finding in an analogous task by presenting words to subjects in either visual or

auditory channels, or in both channels. Subjects were asked to decide if a word or words belonged to a given category. When the same word was presented in each channel, choice response time (RT) was as fast or faster than either single modality. This study demonstrated that the bimodal facilitation effect can apply to more complex and meaningful stimuli than previously shown. In a third study, Kobus and Lewandowski (1986) had shown that on a simulated sonar task, bimodal facilitation for redundant stimuli occurred across dependent measures. They found that the bimodal redundant target condition produced faster and more accurate responses than any other condition. Additionally, the bimodal-different condition (conflicting information in the two modalities) produced the slowest and least accurate results.

The current study was a combination of the above paradigms. This study involved a semantic choice RT task in which category words were presented in various unimodal and bimodal conditions. Since displays now require nigher-level processing of complex information, and sonar operators concurrently engage in verbal communication with the Command Information Center (CIC), this study examined certain cognitive performance of subjects while receiving verbal stimuli in one or two modalities. Therefore, in addition to RT, we investigated semantic decision accuracy and memory recall. Sonar operators were compared with non-operators, and presentation conditions were contrasted to determine the best overall condition for presenting information. The bimodal-redundant condition was expected to be the best performance condition, and sonar operators were expected to out perform non-operators, at least in certain conditions.

Method

Subjects

Subjects were 20 active-duty sonar operators (SO group) from the Anti-Submarine Warfare (ASW) Base in San Diego, California, and 20 non-operators (NO group), solicited from an urban population such that the groups were comparable in age, education, mental ability, and socioeconomic status. The sonarmen each had at least four years of sonar experience, and most were sonar instructors who were considered to be high level performers. The average age of these subjects was 29.2 years (ranging from 23 to 40

years). All subjects would be considered to be in a middle class socioeconomic category based on occupational classification. IQ tests were not administered, but previous research with this population revealed average to above average mental abilities (Lewandowski, Kobus, & Flood, 1987). The range of this group's educational level was from 14 to 20 years ($\underline{M}$ = 14.2 yrs.). Visual and auditory acuity of these subjects was routinely checked, and were within normal (or corrected to normal) limits. The NO group consisted of 20 men ranging in age from 21 to 43 years ($\underline{M}$ = 29.5 yrs.) These men had no sonar experience and no specialized training in visual or auditory detection. On the basis of auditory and visual pre-testing, vision and hearing were determined to be adequate for the experiment. These subjects were all considered to be in a middle class category, based on occupational classification, having a slightly higher mean level of education ($\underline{M}$ = 16.7 yrs.). Mental ability of this group was expected to be above average.

Apparatus

The word decision task was presented via an APPLE II^+ computer. Visual information was displayed on a Zenith 1200 monochrome CT, while auditory words were presented by a "supertalker" speech processor (Mountain, Inc.) through monaural headphones (Maico). RT responses were recorded by depressing specified keys on the computer keyboard. The computer task consisted of 18 blocks (categories) of words (three practices followed by 15 test blocks). Each block contained nine different presentations (trials) of words that were either related or unrelated to a particular category. An example of a block of trials is presented in Table 1. Note that each trial represents a different presentation condition, thus each block has one trial for each of the nine conditions. Within a given block, the trials/conditions were randomly ordered. All subjects received the same order of blocks and trials.

The words used in the task were selected from the Battig and Montague (1969) category norms. They are all one-syllable words of relatively high frequency (A to AA) based on the Paivio, Yuille, and Madigan (1968) frequency tables. Words across conditions were equated to words appearing in the auditory conditions according to frequency, imageability, and length.

Table 1. A Sample Block of Words

Category	Condition	Visual word	Auditory word
Parts of a	Auditory-U		SMILE
Room	Bimodal-different-R	WALL	FLOOR
	Visual-R	RUG	
	Bimodal-different-U	LAMP	CHEESE
	Auditory-R		DESK
	Bimodal-same-R	CHAIR	CHAIR
	Bimodal-different-U	ZOO	SLEIGH
	Bimodal-same-U	STREET	STREET
	Visual-U	WING	

R = Related to category
U = Unrelated

Procedure

All subjects participated voluntarily, and gave written consent. Piloting ensured the task ran smoothly, and that words presented aurally could be identified accurately 90% of the time. Following an explanation of the study, subjects completed a short backgroup questionnaire. Next, subjects were screened for visual or auditory deficits. Visual memory and auditory memory pretests were then administered in counterbalanced order. The visual memory pretest consisted of a printed list of 14 unrelated words. Subjects had 15 seconds to study the list, and then immediately recall, in writing, as many words as possible. The auditory pretest consisted of 14 unrelated words presented in 15 seconds on an audio tape (pre-recorded). Again, the subject had to immediately recall in writing as many words as possible. The pretest prepared subjects for the experimental task, and screened for possible short-term memory deficits.

Subjects were then seated in front of the computer where they read directions from the CRT. The task was also explained by the experimenter. Subjects were instructed that for each block of trials, a category name would appear on the screen. The words to be presented would either belong to that category or not. If any word in a trial was from that category, they should immediately press the "YES" key; if the words presented did not fit the category, they should press the key designated "NO." All subjects used their right hand fingers to respond. The index, middle, and ring finger were lightly rested on the keys to minimize movement time. A third key between the two response keys was depressed whenever the subject was ready to initiate a new trial.

Once the subject made RT responses on all nine trials of a block, the computer informed them that the block was complete. They then had to write the words they remembered from that block on a response sheet in front of them. The instructions emphasized making the fastest decision possible, and then moving on to the next trial, thus not allowing time to rehearse words already presented. In this sense, the word-recall component was much like an incidental memory test. Once subjects completed the three practice and 15 test blocks (about 40 minutes to complete all 162 trials), they were debriefed by the experimenter.

Results

The dependent measures for this task were: 1) response time (RT), recorded in milliseconds, with a median RT determined for each condition; 2) accuracy, as measured by percentage of correct choices; and, 3) recall, as measured by percentage of words recalled per condition. Only eight of the nine trials (each block had one practice trial) were entered into the analyses. The design thus became a 2.42 split plot analysis (see Kirk, 1968) with the between subject variable Group (SO and NO) and the within variables Modality (visual, auditory, bimodal-same word, and bimodal-different words) and Relatedness (related or unrelated to the category).

Initial analyses of the data included three analyses of variance (ANOVAs) with repeated measures. Each analysis was performed on one of the dependent

measures, and encompassed the two groups and four presentation conditions with word Relatedness nested within. These analyses yielded no group differences on any of the dependent measures. Therefore, the group data were collapsed for all further analyses. The mean data (collapsed across groups) are presented in Table 2. The ANOVA of RT data did show significant effects for

Table 2. Mean Performances of All Subjects Across Conditions

Measure	Conditions							
	Visual		Auditory		Bimodal-same		Bimodal-different	
	R	U	R	U	R	U	R	U
RT	804	954	1195	1270	850	1063	970	1496
% Correct	96	93.2	77.7	91.7	94	93.3	91.6	92
% Recall	66.7	36.5	64	29	81.3	37.8	67.2	25.5

RT = Reaction Time
R = Related to category
U = Unrelated to category

both Modality and Relatedness plus an interaction between the two (all $p < .001$). Post hoc comparisons indicated that RT was faster when words were related to a category, and that performance was faster in the visual mode, followed by the bimodal-same condition. The interaction seemed to be due to an unusually slow RT in the auditory mode when the word was related to the category, and an extremely slow RT in the bimodal-different condition when the words were unrelated. The analysis of accuracy data resulted in significant main effects for Modality and Relatedness as well as their interaction ($p < .001$). Subjects were generally more accurate in the related conditions except when the word was presented aurally. Once again, performance in the visual mode exceeded that of the other conditions, followed

closely by the bimodal-same condition. This time, however, accuracy was poorest in the auditory mode, particularly when the word was related to the category.

The analyses of recall data yielded significant effects for Modality and Relatedness ($p < .001$). Word recall was generally higher for related words, and was significantly superior in the bimodal-same condition for related words. Recall for related words in the other conditions did not differ from one another.

Correlational analyses relating the dependent measures across conditions yielded few interesting results. Within a measure (i.e., RT), correlations tended to be high, whereas, between measures correlations tended to be low to moderate. Of most interest, was a check for speed-accuracy trade-offs between RT and accuracy. The correlational data had shown little relationship between these two performances, perhaps, because accuracy was consistently high.

Discussion

The results of this study are generally consistent with similar prior investigations (Lewandowski, Hursh, & Kobus, 1985). Overall, the data indicated that subjects respond faster and more accurately to words presented in the visual modality. They are nearly as efficient when information is redundant and related to a category in the bimodal-same condition. The slightly longer response time (45 ms) probably reflects the longer presentation time of an auditory word (vs. visual presentation time). Despite this slightly longer RT, subjects are able to perform at a highly accurate level, and more importantly, are able to recall the greatest percentage of words in the bimodal-same condition. If one assumes that the recall component reflects the highest level of cognitive processing measured by the task, then one would have to say that the bimodal-same condition is of some benefit. Sonar operators are required to make a variety of complex decisions regarding incoming signals, yet most laboratory studies have investigated only simple lights and tones. The present study has examined bimodal processing of meaningful (complex) information requiring higher lever cognitive activities such as decision making and memory.

The results support the previous work of Lewandowski, Hursh, and Kobus (1985) by demonstrating that the bimodal-same condition is comparable to the better single modality (in this case visual) in RT for a group of 40 subjects. Similarly, the present study is consistent with results of Kobus and Lewandowski (1986) who found that sonar target detection was performed faster and more accurately when the same information was delivered to both modalities rather than one modality or conflicting information in both. This is essentially the pattern of results found in the present bimodal word study. Besides replicating previous research, this study extends this line of investigation by demonstrating the facilitation of memory in the bimodal-same condition. This enhancement of a cognitive performance is promising, and suggests the need for further research on the influence of bimodal information presentation on other cognitive performances. It still appears that in bimodal tasks, regardless of the stimuli and paradigms employed, the bimodal-redundant condition is a desirable one for overall performance, this would also appear to be the case for sonar operation. Designers of sonar systems may want to consider ways of providing dual information (using words or symbols to indicate important data).

The fact that no group differences were found on any of the dependent measures is a little surprising. One might expect that the bimodal task experience of sonar operators would be reflected in better performance than that of non-operators. Perhaps, the word task was different enough from sonar and equally novel for both groups of subjects, such that no differences were found. Similar results (no group differences) have been found in other sonar simulation studies using comparison groups (Kobus, Lewandowski, & Flood, 1987; Lewandowski, Kobus, Flood, & Hoyer, 1988). A next step would be to develop a research paradigm that more closely simulates present sonar operation, yet still allows for experimental manipulation of bimodal processing at higher cognitive levels.

References

Battig, W. F. & Montague, W. E. (1969). Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. Journal of Experimental Psychology Monograph, 80 (No.3, Pt.2).

Kirk, R. E. (1968). Experimental design: Procedures for the behavioral sciences. Brooks/Coles Publishing Company. Belmont, CA.

Kobus, D. A. & Lewandowski, L. J. (1986). Bimodal information processing in a sonar task. Naval Submarine Medical Research Laboratory. Report No. 1075.

Kobus, D. A., Lewandowski, L. J. & Flood, M. M. (1987). Cognitive and personality characteristics of experienced and inexperienced sonar operators. Naval Health Research Center. Report No. 87-15.

Kobus, D. A., Russotti, J., Schlichting, C., Haskell, G., Carpenter, S. & Wojtowicz, J. (1986). Multimodal detection and recognition performance of sonar operators. Human Factors, 28, 23-29.

Lewandowski, L. J., Hursh, S. B. & Kobus, D. A. (1985). Multimodal versus unimodal information processing of words. Naval Submarine Medical Research Laboratory. Report No. 1056.

Lewandowski, L. J. & Kobus, D. A. (1985). The effects of bimodal presentation of stimuli and noise on target detection. Naval Submarine Medical Research Laboratory. Report No. 1058.

Lewandowski, L. J. & Kobus, D. A. (1989). Bimodal information processing in sonar performance. Human Performance, 2, 73-84.

Lewandowski, L. J., Kobus, D. A., Flood, M. M. & Hoyer, W. (1988). The effects of age and experience on sonar performance. Naval Health Research Center. Report No. 88-29.

Miller, J. (1982). Divided attention: Evidence for coactivation with redundant signals. Cognitive Psychology, 14, 247-279.

Nickerson, R. (1973). Intersensory facilitation of reaction time: Energy summation or preparation enhancement. Psychological Review, 80, 489-509.

Paivio, A., Yuille, J.C., & Madiger, S. (1968). Concreteness, imagery, and meaningfulness values for 925 names. Journal of Experimental Psychology, 76(No.1,Pt.2).

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