XVI. SENSORY AIDS RESEARCH

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A. A VISUAL AND A KINESTHETIC-TACTILE EXPERIMENT IN PATTERN RECOGNITION

In sensory aids research we are often concerned with the performance of a human subject in a task for which the normal input sensory modality is replaced by an alternative modality. In addition to inherent differences in the information intake and processing capabilities of two sensory modalities, there are, in each modality, purely mechanical effects that significantly modify performance, and thus complicate the problem of sensory replacement. The experiment reported here compares human performance in a simple pattern-recognition task with the visual and the kinesthetic-tactile sensory modalities. Such an experiment serves to illustrate both the inherent information-processing capabilities and the mechanical factors that influence performance.

1. Visual Experiment in Pattern Recognition

In the visual part of the experiment, 21 subjects were shown a sequence of 13 patterns, each consisting of a horizontal row of six black or white squares. The patterns were exposed for 6 discrete time durations ranging from 30 to 500 msec. The subjects responded by placing X's on the answer sheet in each position where a white element appeared. The patterns were actually exposed with white signal boxes on a black background. The ambient light level was, therefore, reasonably constant, and the stimulus intensity well above threshold. The photographs in Fig. XVI-1 show sample patterns.

Performance in this task was good. An over-all error rate of 0.255 per cent was noted for all patterns and all times. (An error was arbitrarily defined as any mismarked square; mismarked either through omission of a correct response or insertion of an incorrect response.) The percentage of error versus exposure-time duration for all patterns and for the test group (3 white squares out of 6) is shown in Fig. XVI-2. Figure XVI-3 shows the relative number of errors made on each of the 13 test patterns. The ordinate scale is normalized to the number of errors on the pattern with the fewest errors. Figure XVI-4 shows the distribution of errors with respect to the stimulus positions. The stimulus patterns were so arranged that the subjects would make approximately the same number of responses for each position for the whole experiment.

The most interesting feature of the experimental results is the peak in the error rate versus exposure duration curve in the vicinity of 60-msec exposure time. This tendency is present in each individual pattern (at least when there is a sufficient number of errors to justify this statement). No explanation is now offered for this result, but

Fig. XVI-1. Sample patterns for visual experiment.

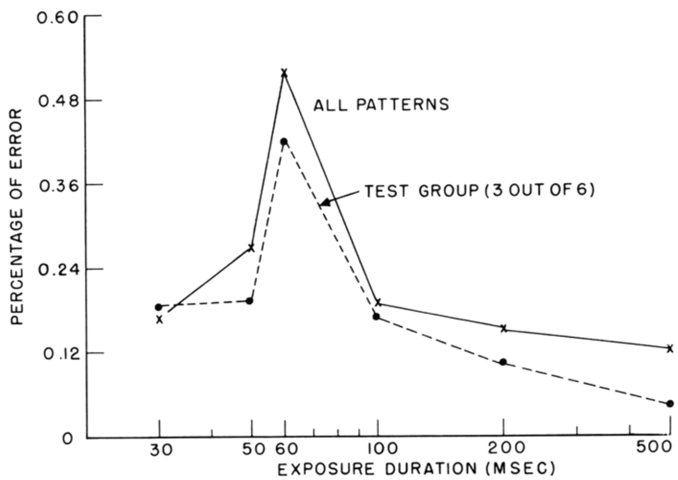

Fig. XVI-2. Percentage of error versus stimulus duration in the visual experiment.

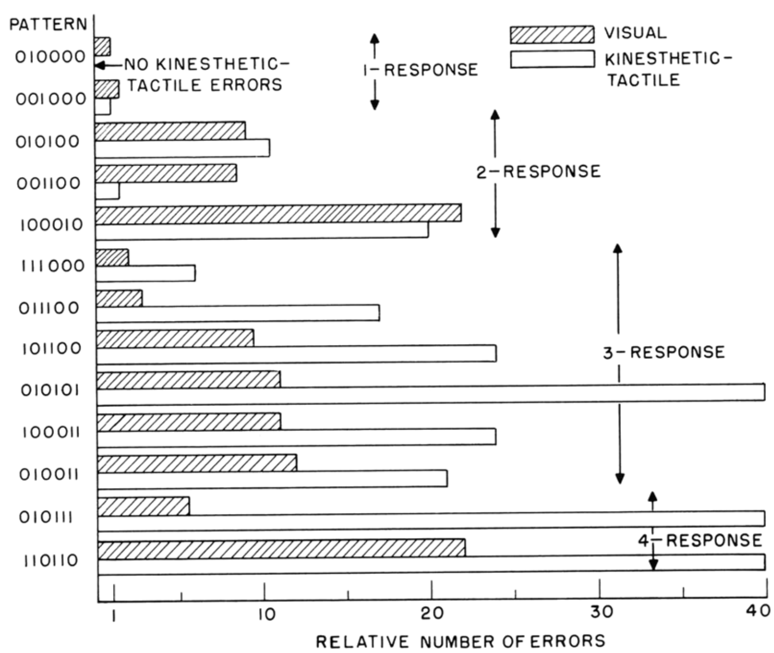

Fig. XVI-3. Relative number of errors between patterns.

further experimentation is in progress. However, one of the authors (R. J. M.) feels that the pattern exposures of approximately 60-msec duration produced the most pronounced afterimage. Furthermore, it is more difficult to stabilize the position of the afterimage in the visual field for exposures of this duration than for any other exposure time used in the experiment. (This peak in the error rate was not noted in the kinesthetic-tactile experiment.)

For a 100-msec exposure time of patterns from the test group the subjects received information at a rate of less than 30 bits/sec, and their response was essentially errorless (0.19 per cent). The curve in Fig. XVI-2 indicates that the subjects who took this test were capable of an information intake of approximately 90 bits/sec with the same error rate for much shorter exposure times (30 msec). It should be noted that not all subjects behave in this manner. Some of the 21 subjects made virtually no errors during the whole experiment.

Figure XVI-3 illustrates how the errors were distributed for the patterns presented. Note that the positions of the white squares in the pattern are indicated by "1". Despite the fact that a pattern of 2 white squares and 4 black squares might be considered to be informationally equivalent to its complement (4 white squares and 2 black squares), higher error rates are noted in patterns in which the subject's response is "four X's." In the 3-out-of-6 response patterns the situation is different, since both complementary pairs require the same number of responses. Pattern No. 7 and pattern No. 10 are complements, yet the error rate for No. 10 is three times higher. Examination of the patterns shows that the 3-in-a-row response pattern of No. 7 is probably much simpler to encode than the separated response pattern of No. 10. Patterns No. 8 and No. 11 are also complements; the same error rate and general characteristics of the response

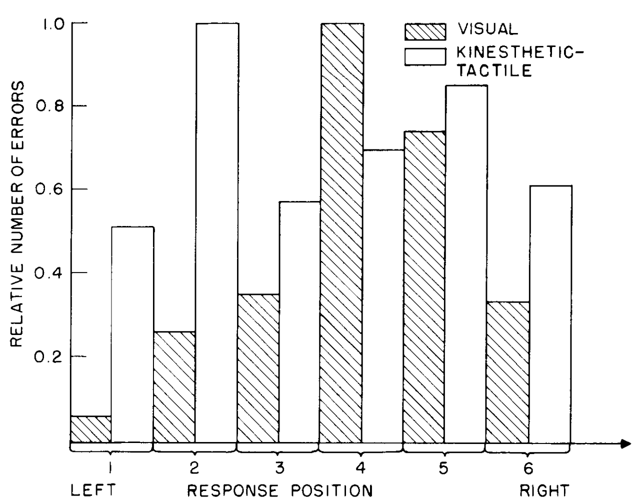

Fig. XVI-4. Relative number of errors versus response position or stimulated finger.

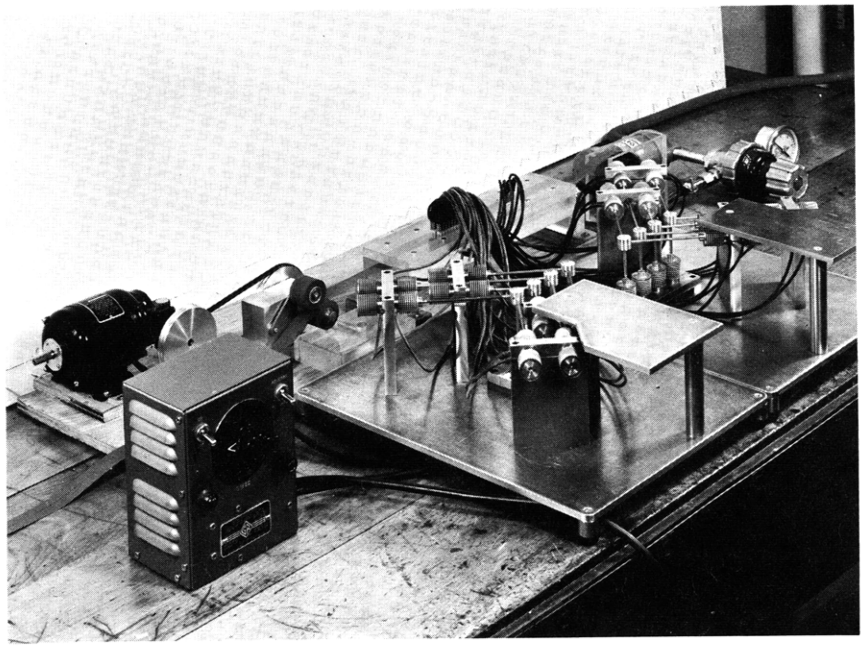

Fig. XVI-5. Air-driven finger stimulator.

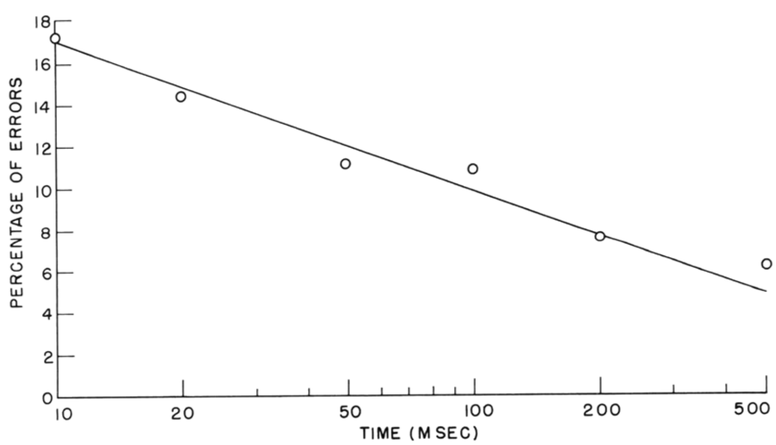

Fig. XVI-6. Percentage of error versus exposure time for test patterns in the kinesthetic-tactile experiment.

pattern are noted. This phenomenon supports the general conclusion that informationally equivalent tasks are not always psychophysically equivalent.

Referring again to Fig. XVI-4, the fact that fewer errors are shown for the subjects in positions 1 and 6 is in general agreement with many published results. The preponderance of errors in position 4, despite the fact that the subjects' eyes were, in general, fixated on this position, is more difficult to explain. This result is in contrast with results published by Averbach and Coriell (1) in a study of short-term memory in vision. They report that when the subject is able to assimilate information from a linear array for a fixed time duration, he makes the fewest number of "recall" errors in the central positions. We plan to perform experiments in this laboratory to clarify this point.

2. Kinesthetic-Tactile Experiment in Pattern Recognition

The kinesthetic-tactile experiment consisted of simultaneously moving some combination of the subject's fingers. Only six fingers were used: the index, middle, and fourth fingers of each hand. The various combinations of finger movements corresponded to the 13 black-and-white 1×6 matrix patterns used in the visual part of the experiment. The apparatus consisted of eight finger rests, six of which were connected in this experiment. The six rests could be moved in the vertical direction by Sylphon bellows according to a program punched on paper tape. The movements were at least 1/8 inch in all cases, which is well above threshold (2). Figure XVI-5 shows the apparatus and the air valve, which uses punched-paper tape as the slide. A shield was placed in such a way that the subject could not see his hands during the experiment. On this shield there was a diagram that gave the number labels for the six fingers used in the experiment. The fingers were numbered 1-6, from left to right. Six discrete time durations, during which air pressure was on the bellows, were used to cover the range 10 msec-500 msec. The subject responded orally by indicating the numbers of the fingers that were moved.

The combined error rate for all times and all patterns was 10.5 per cent. (An error is defined as either reporting a finger movement that did not occur, or as failing to report a finger movement.) The percentage of error versus exposure-time duration for the test group of patterns is shown in Fig. XVI-6.

Figure XVI-4 shows the distribution of errors with respect to the finger that was stimulated. This distribution can be explained if one assumes that most errors in finger localization are made between adjacent fingers of the same hand. This assumption was checked in an auxiliary experiment in which all combinations of the 2-out-of-6 patterns were presented to two subjects. Table XVI-1 shows the confusion matrix obtained for the errors. Thus the relatively low error rate obtained for fingers 3 and 4 (Fig. XVI-4) is probably due to the fact that they are on different hands, and the low rate for fingers 1 and 6 probably results from the fact that these were the "outside"

Table XVI-1. Stimulus-response matrix for all combinations of 2-out-of-6 finger movements.

STIMULUS \ RESPONSE	1	2	3	4	5	6
1	38	1	1			
2	4	24	11		1	
3		7	33			
4				30	10	
5				2	35	3
6					3	37

fingers in the experiment.

Figure XVI-3 shows the relative number of errors made on each of the 13 patterns. The percentage of error increased markedly with the number of fingers stimulated. It appears that complementary patterns with unequal numbers of fingers stimulated would give significantly different error rates. Patterns in which the stimulated fingers were adjacent, for example, 111000, resulted in a much lower error rate than patterns in which alternate fingers were stimulated, for example, 010101.

3. Comparison of Visual and Kinesthetic-Tactile Results

Since the stimulus intensities for each modality were well above threshold intensities (although no attempt was made to equate the stimulus energy for each modality), it can be concluded that all subjects perform much better in the task when visual information intake is used. Error rates are an order of magnitude higher for the kinesthetic-tactile experiment.

The assumption that complementary patterns are informationally equivalent is not upheld by the experimental results for either visual or kinesthetic-tactile stimulations. The reasons, however, are different. When the visual observer is asked to note the positions of the white squares and report these positions, he does not appear to encode the pattern as a whole, but rather to "measure" the distance between stimulus squares. This results in higher error rates on the complementary patterns with the greater distance between response positions. (See patterns No. 7 and No. 10, Fig. XVI-3.)

With tactile stimulation, complementary excitation (movement - no movement) appears to be even less useful as an encoding tool for the subject. This can be seen from the marked increase in error rate as one goes from 1 stimulus out of 6 to 4 stimuli out of 6 (Fig. XVI-3).

In kinesthetic-tactile stimulation, the ability to dichotomize the stimulus because of the use of two hands, in contrast to visual stimulation, results in position errors for the two modalities that are significantly different in positions 3 and 4. In the visual display, the center positions are most often confused because the subject presumably measures distance from the end. This conclusion is borne out in both the position-error curve (Fig. XVI-4) and the pattern-error curve (Fig. XVI-3).

A simple model of visual information transmission which assumes that performance should continue to improve as the stimulus duration is increased (because of greater stimulus energy at constant intensity) is not consistent with the observed data for the visual sense. The sudden increase in error rate when 60-msec exposure times are used is probably due to some "mechanical" aspect of the visual process and is not present in the tactile experiment.

The results and conclusions presented in this report are preliminary. No special significance is attached to the numerical results; they are merely considered to be illustrative.

J. C. Bliss, R. J. Massa

References

1. E. Averbach and A. S. Coriell, Short-term memory in vision, Bell System Tech. J. 40, 309-328 (1961).

2. J. C. Bliss, Discriminatory thresholds for the sense of touch, Quarterly Progress Report No. 57, Research Laboratory of Electronics, M. I. T., April 15, 1960, pp. 182-183.