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SPATIAL CODING OF TACTUAL STIMULATION[1]

FRED ATTNEAVE[2] AND BRADDIE BENSON

University of Oregon

Responses were paired with stimulation from six vibrators, fixed in a T formation, which *S* contacted with the three middle fingers of each hand. After 12 learning trials, the relationship between fingers and vibrators was completely changed by reversing *S*'s hands. In this transfer condition, some *S*s were allowed to respond spontaneously to the stimuli; others were asked specifically to give the same responses to the same fingers or, alternatively, the same responses to the same vibrators. Results showed that *S*s learned both types of association and could transfer rather well on either basis. For *S*s with unrestricted vision, associations with vibrators (i.e., locations in physical space) were clearly stronger than finger associations; no such difference was found for blindfolded *S*s. This result suggests that spatial location is represented primarily in visual terms, even when based on input from another modality.

The point has been made many times—most graphically, perhaps, in Brunswik's (1947) "lens analogy"—that behavior is much more simply predictable from the external situation, i.e., from "distal stimuli," than from events at the receptor surface, or "proximal stimuli." In at least some cases, it appears that receptor events (as opposed to representations of the world derived from those events) are incapable of entering into associations or forming memory traces. Thus Attneave and Olson (1967) found that when the heads of *S*s were tilted after the learning of associates to different line orientations, an invariant relationship between retinal orientation and response produced essentially no transfer; physical or objective invariance, on the other hand, made for practically perfect transfer. A subsequent study by Attneave and Reid (1968) indicated that in such associations the antecedent member is orientation relative to an internal reference system, the vertical of which is normally but not necessarily kept in correspondence with the objective vertical.

Whether principles of this sort may be generalized to other modalities, and if so, how, is not immediately obvious. Suppose various fingers are tactually stimulated, with a response assigned to each. Will associations be made to particular fingers, or to particular places or objects in the outside world? In a somewhat casual pilot version of this experiment, blindfolded *S*s grasped a pair of bars arranged in a T formation so that the upper hand was horizontally oriented and the lower hand vertically oriented. The *E* then proceeded to touch the eight knuckles (exclusive of thumbs), pairing a letter of the alphabet with each. After several trials, during which *S*'s responses were confirmed or corrected, his hands were switched, the lower hand being placed on the upper bar and the upper hand on the lower bar, and he was told simply to give the first response that came to mind whenever a knuckle was touched. Of seven *S*s, five gave responses that were predominantly appropriate to fingers; responses of the other two were predominantly appropriate to spatial locations.

It should be noted that the latter two *S*s were responding to spatial location in quite an abstract sense, since the stimulating *object*, *E*'s finger, had no constant location, but moved from place to place to deliver the stimulation. It was decided that a more interesting and realistic situation would be one in which the stimulating objects maintained stable locations in the external world: accordingly, fixed vibrators were used as

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[2] Requests for reprints should be sent to Fred Attneave, Department of Psychology, University of Oregon, Eugene, Oregon 97403.

stimulating devices in the experiments to be reported.

EXPERIMENT I

Method

Subjects.—The *S*s were 10 paid University of Oregon student volunteers, 6 male and 4 female.

Apparatus.—The portion of the apparatus with which *S* was concerned is shown in Fig. 1. Three inaudible finger vibrators were recessed in each of two aluminum tubes rigidly mounted in a T formation and attached to a vertically adjustable wall bracket. The *S*'s three middle fingers were held in contact with each set of vibrators. Stimulation to the fingertip was a 60-Hz. vibration of moderate intensity.

The control apparatus, located behind *S*, included a set of six button switches which activated the vibrators by way of a completely flexible patch panel. The latter enabled *E* to vary assignment of responses to stimuli between *S*s without the inconvenience of altering the relationship between buttons and responses. A clock was automatically started at the onset of each stimulus and stopped by *S*'s vocal response by means of a throat microphone and voice key.

Procedure.—In the initial phase, a simple paired-associate learning procedure was followed. The stimuli were vibrations to six different fingers in the positions indicated previously; responses were six letters of the alphabet (*b, f, j, m, q, s*), assigned to stimuli by a separate random permutation for each *S*. Half of the *S*s began with the right hand on the upper bar and the left hand on the lower; for the other half, these positions were reversed.

At the beginning *S*'s fingers were positioned on the vibrators, which were then activated in rapid succession to show him how they felt. The first instructional trial followed immediately, with a bare minimum of instructions: "I'm going to teach you a code. This is [*m*] . . . , this is [*j*] . . . ," etc. Whether "this" should be taken to refer to the stimulation of a particular finger or the activity of a particular vibrator was carefully left unspecified, but there was no indication that *S*s viewed the learning task as an ambiguous one. In the second instructional trial, *E* again supplied the response letters. The *S* was then asked to give the correct letters, responding as rapidly as possible. Twelve learning trials (72 single stimuli) were given, during which *S* was corrected when he made an error.

Order was randomly permuted on each trial. Interstimulus interval was about 10 sec., allowing *E* to correct errors, record reaction time, and give a "ready" signal before the next presentation.

After the 12 learning trials, *S* was then asked to exchange the positions of his left and right hands (see Fig. 1). He was told:

> Now that you have switched hands, you can see that I *might* ask you to do either of two different things. I could ask you to give the letters you have learned either to the same *fingers* or to the same *buzzers*. Actually, I don't care which you do; in fact, I don't even care whether you are consistent or not. All I ask is that you give me the first letter that pops into your head each time, *without stopping to think*. Don't try to plan in advance what you are going to say, and don't worry any more about being right or wrong. Just be completely spontaneous, and respond as fast as you can. O.K.?

Two transfer trials were conducted on this basis, without feedback. At the end, *S* was asked which of the two transfer response conditions (letters to fingers or letters to vibrators) he thought would have been easier and why.

Results

Of the pooled responses from all *S*s on both transfer trials, 54% were correct for vibrators, 12% were correct for fingers, and 34% were incorrect by either criterion. Difference scores for individual *S*s (vibrator responses minus finger responses) yielded $t(9) = 3.07, p < .02$.

Six *S*s expressed the opinion that a vibrator transfer condition would be easier than a finger transfer condition; the remaining four

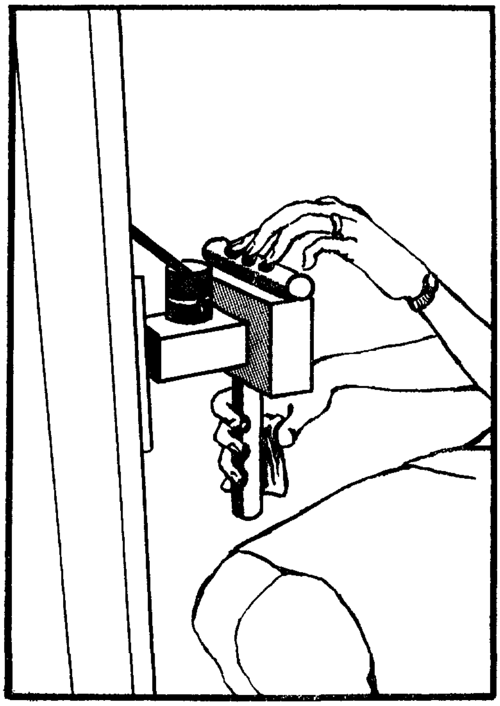

FIG. 1. The stimulating apparatus, showing *S*'s fingers in contact with the six vibrators.

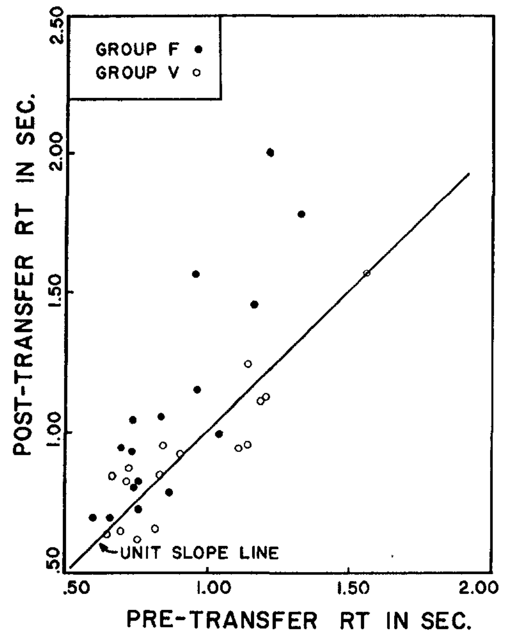

FIG. 2. Data from Exp. II, in which *S*s had unrestricted vision. (Each *S*'s mean latency on the two transfer trials is plotted against his mean latency on the last four pretransfer trials.)

thought the reverse. Two of the former suggested that the vertical-horizontal arrangement of the apparatus facilitated vibrator associations, and a third—anticipating a conclusion that can be drawn from the following experiments—spoke of *visually* identifying the letters with the vibrators.

EXPERIMENT II

The results of Exp. I show a marked predominance of vibrator associations over finger associations, but they do not tell us how well *S*s *could* have responded on either of the two bases with the basis specified. Experiment II, though like the first in other respects, employed two groups which were told at the time of transfer whether to respond on the basis of proximal or distal invariance.

Method

Subjects.—The *S*s were 32 paid student volunteers. Each of the two groups contained 8 male and 8 female *S*s.[3]

Apparatus and procedure.—Apparatus was the same as that used in Exp. I. Procedure was identical to that in Exp. I through the first two sentences of the transfer instructions, "Now that you have switched hands, you can see that I *might* ask you . . . ," etc. Thereafter, instructions to Group F and to Group V, respectively, differed by the terms enclosed in parentheses:

> What I actually want you to do is to keep the letters in correspondence with the same (fingers) (buzzers) as before. Whenever one of (your fingers is vibrated) (the buzzers vibrates), give me the letter that was previously correct for that (finger) (buzzer), ignoring the fact that (the finger is in a different place) (a different finger is on that buzzer). Try not to make errors, but be just as fast as you can. Do you understand what you are to do? . . . All right, let's go ahead.

Results

In Fig. 2, each *S*'s performance on the transfer task is plotted against his performance on the four preceding trials. It is evident at once that better transfer was associated with vibrator invariance than with finger invariance: 13 of the 16 *S*s in Group F were to some degree slowed down on the transfer task, whereas in Group V only half of the *S*s were slower on the transfer task, the other half faster.

A "transfer loss" score, consisting of mean time on the two transfer trials minus time on the last four pretransfer trials (i.e., vertical deviation from the unit-slope line in Fig. 2), was calculated for each *S*. By this criterion the mean (over *S*s) transfer loss was .22 sec. for Group F and −.01 sec. for Group V. Distributions of individual loss scores show that Group F was considerably more variable than Group V. This difference in variability was highly significant, F (15, 15) = 4.2, $p < .005$. In testing the significance of the difference between means, we compensated for inhomogeneity of variance by the formula presented in Guenther (1965, p. 147), which entailed a reduction in degrees of freedom from 30 to 20. Even with this adjustment, a significant superiority of Group V over Group F is demonstrable, t (20) = 3.40, $p < .01$.

To try to summarize these results in a

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[3] The question of sex differences may be dismissed at once; careful data inspection yielded no suggestion of any such differences in either this or the subsequent experiment.

single statement: it appears that all *S*s formed strong vibrator associations, whereas finger associations were strong in some *S*s, less so in others. The superiority of Group V should not obscure the fact that *both* groups really did quite well on their respective transfer tasks. This is particularly evident in the extremely low error rates: Group F had 93% correct responses on the transfer trials; Group V, 99%. This difference was not significant, but with so few errors the test is not very powerful.

An alternative to the analysis of transfer loss scores is a covariance analysis in which a regression function relating posttransfer to pretransfer performance is calculated, and transfer scores are in effect considered as deviations from predicted values rather than from pretransfer values directly. (The transfer loss analysis is equivalent to a covariance analysis that employs an a priori prediction function of unit slope.) The covariance method assumes that the regression lines for the groups being compared will not differ greatly in slope. In the present case, however, the two slopes are markedly and significantly different: 1.63 for Group F and .86 for Group V. This difference is interesting in its own right. Roughly, the situation is as follows: at all levels of pretransfer performance, Group V *S*s tended to show better transfer than Group F *S*s, but the difference was greater for slow *S*s than for fast ones (see Fig. 2). The causal relationship may be the other way about, however: it may be that association of responses to *both* fingers and vibrators made for faster reactions, prior to transfer, than association to vibrators alone. In any case, the greater variability of transfer loss scores for Group F than for Group V is essentially attributable to this interaction, since residual variance about a unit-slope prediction line is nearly minimal for Group V, but not so for Group F.

If we simply ignore (i.e., average out) the slope difference and proceed in the conventional manner, we obtain a covariance-adjusted F (1, 29) = 12.35, which is sufficiently in excess of the nominal .01 level (7.60) to overcome moderate reservations. It may be, however, that a more legitimate test of significance is provided by the original analysis of transfer loss scores, in which due allowance is made for the inhomogeneity of variance which that procedure involves.

TABLE 1

Number of *S*s in Exp. II Who Preferred Each Basis for Transfer

Preference	Own group	Other group	Total
Finger	8	3	11
Vibrator	13	7	20
Total	21	10	

Note.—Vertically, *S*s are classified by expressed preference for finger invariance vs. vibrator invariance. The horizontal classification shows whether this constituted a preference for the basis on which *S* had actually been asked to transfer, or for the other. Thus, Group F falls on the left diagonal of the table, Group V on the right diagonal. One *S* (in Group F) who said there would be no difference in difficulty is unclassified.

As before, all *S*s were asked at the end whether they would have preferred a transfer condition based on finger invariance or on vibrator invariance. In Table 1 their responses are classified by finger vs. vibrator preference and according to whether the preference did or did not coincide with the transfer condition in which *S* had just been run. It is not surprising that two-thirds of the *S*s preferred the vibrator condition; what is interesting, or at least amusing, is that two-thirds of the *S*s also felt that the condition to which they had been assigned was the easier. (This effect is seen even more strongly in Exp. III.) The following comments are representative of persons preferring finger transfer: "wasn't a visual response, it was a sensory response"; "learned through feeling instead of looking"; "seems more natural." Representative comments from those preferring vibrator transfer included the following: "because of the difference between horizontal and vertical"; "remembered by picture association"; "keyed off the apparatus"; "learned by sight"; "because you have a spatial idea of the apparatus." Again, note the repeated references to vision.

Experiment III

The reader may recall that the pilot study, unlike Exp. I and II, seemed to show a predominance of associations to fingers rather than to locations in external space. A difference already mentioned was that the pilot study did not employ separate stimulating objects with fixed locations. Another difference was that pilot *S*s were blindfolded, whereas *S*s in Exp. I and II had full vision. The matter of blindfolding at first seemed irrelevant, since the information transmission from apparatus to *S* was entirely tactual in any case. However, the numerous comments of *S*s suggesting the use of visual imagery, or of a visual reference system, led us to reconsider this assumption. Accordingly, we decided to replicate Exp. II with *S*s blindfolded. The replication was otherwise as exact as we knew how to make it, with 32 new *S*s obtained from the same source and balanced for sex as before. The *S* never saw the stimulating apparatus until the end of the session, since it was covered with a cloth when he entered the room.

Results

For the blindfolded *S*s (see Fig. 3) there is not the slightest evidence that either basis for transfer was better than the other. The mean transfer loss was now almost identical for both groups: .19 sec. for Group F and .20 sec. for Group V; cf. the mean loss of .22 sec. for Group F of Exp. II. The distributions of loss scores are quite similar to each other and to the distribution for Group F in Exp. II. It seems evident that the goodness of performance immediately prior to transfer in Exp. III was dependent on *both* proximal and distal aspects of stimulation, since the disturbance of *either* invariance impaired performance.

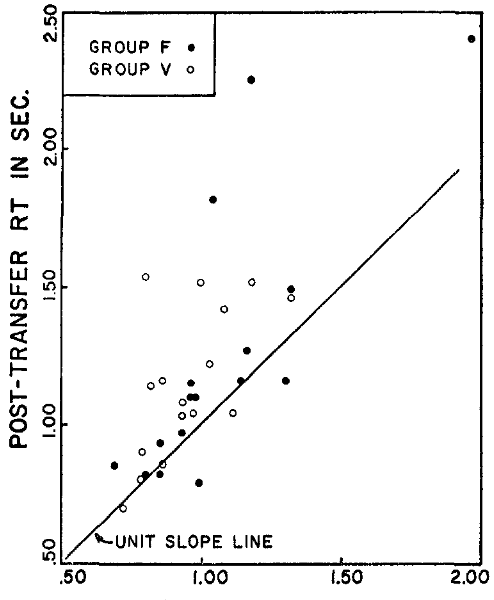

FIG. 3. Data from Exp. III, in which *S*s were blindfolded; plotted as in Fig. 2.

TABLE 2

NUMBER OF *S*S IN EXP. III WHO PREFERRED EACH BASIS FOR TRANSFER

Preference	Own group	Other group	Total
Finger	12	3	15
Vibrator	13	3	16
Total	25	6	

Note.—Explanation as in Table 1. Again, one indifferent *S* (of Group F) is unclassified.

The present data do not violate the assumptions of a covariance analysis: the difference between slopes of regression lines for the separate groups (Group F, 1.30; Group V, 1.02) was well within limits of sampling error. This method yielded a covariance-adjusted $F\ (1, 29) = 0.2$, which again is completely unsuggestive of differential transfer.

Comparing transfer loss scores across experiments, we can demonstrate that Group V in Exp. II was significantly different from its counterpart in Exp. III with respect to both variance, $F\ (15, 15) = 3.27$, $p < .025$, and mean, $t\ (21) = 3.85$, $p < .001$, making due allowance for inhomogeneity of variance. Covariance analysis yielded a similar result (necessarily so, since the regression slopes for the two vibrator groups, .86 and 1.02, are both close to unity), $F\ (1, 29) = 12.06$, $p < .01$. It may be noted that the two vibrator groups attained almost identical levels of latency prior to transfer; their subsequent performance shows, however, that those *S*s who could see had formed better associations to locations in physical space than those who were blindfolded.

Both groups of Exp. III showed good transfer in terms of errors: Group F was correct on 84% of the transfer responses, Group V on 94%. This difference was not significant.

Expressed preferences for the two possible transfer conditions are tabulated in Table 2. The only effect that now appears (cf. Table 1) is a strong tendency ($p < .001$) for *S* to prefer the condition in which he was actually placed. The following comments are representative of *S*s preferring finger transfer: "memorized letters to fingers; if I could have seen it would have made a difference"; "associated letters with my fingers . . . personal, not a machine"; "got to be a reflex." Representative comments from *S*s preferring vibrator transfer included the following: "associated area to induction of stimulus"; "learned spatially"; "memorized according to the bar"; "correlated with parallel [sic] and horizontal, memorized to the position." It may be mentioned that there was no relationship approaching significance, in either this or the previous experiment, between expressed preference and transfer loss within individual groups.

DISCUSSION

Before considering differences, let us emphasize that *all* the groups of Exp. II and III showed remarkably good transfer, whether blindfolded or not and whether asked to transfer on the basis of proximal stimulation or object location. None of the groups made many errors on transfer, and none of the groups was slowed down on the transfer task by much more than .2 sec.: cf. the more striking disruption of proximal transfer performance in the case of the visual stimuli studied by Attneave and Olson (1967). Clearly, associations were made to both distal and proximal stimuli in the present situation; an operationally equivalent statement would be that *S* learned the spatial location of the stimulating object paired with each response *and* which of his fingers was in contact with the object in that location. Although we found associations with spatial locations to be predominant in Exp. I and II, it is entirely possible that one could make finger associations predominant by a variety of means, including the use of a less distinctive spatial configuration of objects, the use of a single, moving stimulator, and almost certainly by telling *S*s initially to associate to fingers rather than to spatial locations. (See Attneave & Reid, 1968, for one example of the effect of instructions on *S*'s reference system.)

The fact that people associate better to spatial locations with full vision than when blindfolded, in what is ostensibly a purely tactual experiment, is of considerable theoretical interest. The statement that associations are formed with spatial locations is not to be taken literally in any case, because physical space is not a part of the nervous system: what is meant, and what the demonstration of such associations requires us to suppose, is that the nervous system contains some model or representation of physical space, within which certain invariant descriptors stand for particular objective locations. The difference that we found between seeing and blindfolded *S*s, considered together with *S*s' verbal comments, supports the belief that space is represented primarily in visual terms, whether the relevant input is from vision or another modality. Even the blindfolded *S* may have mapped the stimuli into an imagined visual space, which he constructed from tactual and kinesthetic information. A perceived visual space would have vastly more detail and articulation than an imagined one, however, and might be expected to provide a correspondingly better reference system within which to specify and discriminate spatial locations.

We considered the possibility that *S*s in Exp. II might have provided differential visual stimulation for themselves by lifting, wiggling, or otherwise moving the vibrated fingers. No such behavior was ever observed, but since *E* was occupied with the control apparatus, it could have occurred unnoticed. However, *S* could not see all his fingers equally well: those on the top, horizontal bar were clearly visible, whereas those on the lower, vertical bar were almost completely occluded from vision by the apparatus (see Fig. 1). Hence, if the superior transfer performance of Group V, Exp. II, is attributable to visually localized finger movements, it also follows that transfer within that group should have been better for the upper three vibrators than for the lower three. In fact, mean transfer loss was —.03 sec. for the upper vibrators and .00 sec. for the lower (cf. the loss of .20 sec. for Group V, Exp. III). Since this difference is not even suggestive of the operation of anything but chance, it seems quite unlikely that visual coding was achieved by finger movements.

There is another way in which *proximal* visual stimulation may well have covaried with tactual stimulation in Exp. II, in that *S* may have systematically directed his gaze to or toward the vibrated finger. The hypothesis that tactual-to-visual mapping was accomplished in this manner is a tenable one, but somewhat implausible in view of the evidence, cited earlier, that associations are not formed with the retinal stimulus.

The idea that input to one modality may be mapped or coded into the representational system of another is not a new one. There is strong evidence, e.g., that visually presented sequences of words or letters are temporarily held in auditory memory (Conrad, 1963; Sperling, 1963). It appears that different modalities have qualitatively different facilities for data handling and that sensory information may be transferred to the modality best able to process and store it.

REFERENCES

Attneave, F., & Olson, R. K. Discriminability of stimuli varying in physical and retinal orientation. *Journal of Experimental Psychology,* 1967, 74, 149–157.

Attneave, F., & Reid, K. W. Voluntary control of frame of reference and slope equivalence under head rotation. *Journal of Experimental Psychology,* 1968, **78**, 153–159.

Brunswik, E. *Systematic and representative design of psychological experiments: With results in physical and social perception.* Berkeley: University of California Press, 1947.

Conrad, R. Acoustic confusions and memory span for words. *Nature,* 1963, **197**, 1029–1030.

Guenther, W. C. *Concepts of statistical inference.* New York: McGraw-Hill, 1965.

Sperling, G. A model for visual memory tasks. *Human Factors,* 1963, **5**, 19–31.

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