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VOLUNTARY CONTROL OF FRAME OF REFERENCE AND SLOPE EQUIVALENCE UNDER HEAD ROTATION[1]

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Transfer studies show that people normally associate responses with physical rather than retinal stimulus orientations. In this study experimental *S*s were instructed to adopt a head-anchored reference system ("Think of the top of your head as 'up'.") with heads tilted, during either initial learning or transfer. These instructions strongly facilitated transfer based on retinal invariance with head position changed. Moreover, faster response to retinal verticals and horizontals than to retinal diagonals with head tilted, prior to transfer, was significantly predictive of superior performance on the transfer task, which required same response to same retinal stimulus with head upright. Conclusions: (*a*) Invariance of perceived or phenomenal slant (rather than either physical or retinal slant) is the critical determinant of transfer. (*b*) Likewise, lines *perceived as* vertical and horizontal tend to evoke faster responses than those perceived as obliques. (*c*) Phenomenal slant depends on the orientation of a frame of reference, which is subject to voluntary as well as proprioceptive control.

In discrimination reaction time (DRT) experiments recently reported by Attneave and Olson (1967), physically vertical and horizontal lines evoked faster responses than physically diagonal lines, whether *S* viewed the stimuli with head upright or with head tilted 45° so that physical and retinal orientation were in opposition. A transfer study in the same context showed further that identifying responses were associated with physical rather than retinal orientation: When head tilt was changed by 45° after a learning period, *S*s had no difficulty giving the same responses to the same physical stimuli, but typically showed marked disruption when required to give the same responses to the same retinal stimuli.

In the case of three atypical *S*s who showed good transfer on the basis of retinal invariance when shifted from head upright to head tilted, there was some suggestion that they did so not by virtue of any simple, static connections, but rather by rotating the whole orientational reference system into correspondence with the axes of the head.

The set of hypotheses that the authors now propose to investigate may be stated briefly as follows: (*a*) the orientation of a stimulus is perceived (described, categorized) in terms of a subjective frame of reference; (*b*) this reference system is labile; (*c*) normally it is kept in an invariant relationship to the physical vertical and horizontal; (*d*) however, it is subject to some degree of voluntary control such that under special instructions it can be kept in invariant relationship to the axes of the head; and (*e*) it is the stimulus *as perceived* (i.e., the description of the object within the prevailing reference system) that constitutes the antecedent term when S-R associations are formed or exercised.

If these hypotheses are correct, in-

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structucting S to *think of the top of his head as 'up'*, when his head is tilted, might be expected to alter radically the associations between physical orientations and identifying responses, either at the time of learning or at the time of recall. More specifically, it was predicted that this set on the part of S would remove or diminish the difficulty of maintaining a constant response to a retinally invariant stimulus under head rotation. The effects of such instructions on performance under two different conditions of transfer are investigated in the present study.

Somewhat incidentally, the authors were also interested in determining whether the attempted voluntary shift in frame of reference would alter the relative difficulty of identifying diagonals vs. horizontals and verticals.

Method

Subjects.—The Ss were 64 (4 groups of 16) University of Oregon undergraduate volunteers, who were paid for participation. All met a criterion of 2/2 acuity with no detectable astigmatism in the right eye.

Materials.—For the major portion of the study, the 32 stimulus cards described by Attneave and Olson (1967) were used again. Each contained a single line segment .5° long, positioned 2° from a central fixation point in a circular field. The lines varied over four orientations (horizontal, vertical, and the two diagonals) and eight positions relative to the fixation point (above, upper right, etc.).

Instructional or practice materials included the following: (*a*) four cards illustrating the four slants with segments centered in the field; under some conditions these cards contained the words TOP and BOTTOM positioned either at the physical top and bottom of the field or, alternatively, rotated 45° clockwise; (*b*) four cards illustrating the four slants with segments located 2° from a central fixation point in randomly chosen directions; and (*c*) four cards each containing eight segments (two examples of each slant) randomly ordered in a circular array 2° from the center of the field.

Apparatus.—A two-field tachistoscope (Gerbrands) was used to present S's right eye with a circular field 7 in. in diameter 2 ft. away. An adjustable headpiece held S's head either upright or tilted 45° clockwise. The pre- and postexposure field, which contained a central fixation point, and the stimulus field containing a line segment were matched in luminance at 7½ mL.

When S pressed a hand switch, the stimulus field was exposed for $\frac{1}{10}$ sec. and a clock was started. The S's vocal response turned off the clock by means of a voice relay.

Procedure.—The S was told, without elaboration, that the purpose of the experiment was to study his reaction time under several different conditions. He was told that on each trial he would look into the tachistoscope, keeping his head fitted snugly into the headpiece, and fixate the dot in the preexposure field. When he pressed the hand switch a short line would flash on the screen. The line would have one of four slants, each with a different name. The S was to say the name of the line as quickly as possible after its exposure. He was then shown each line, centered in the field, and told its name. The names (which were counterbalanced over slants within each group) were *Adam, Abner, Albert,* and *Andrew.* Each slant was then shown off-center, as in the main body of the experiment; S was told that these were samples of the actual stimuli and asked for the name of each. Finally, before any reaction times were taken, he was shown the cards with eight lines in a circular array, and asked to go around the circle giving the name of each. This process was continued with successive cards to a criterion of one perfect circuit (two correct responses to each slant).

Reaction times were then taken on 64 trials involving two successive random permutations of the 32 stimulus cards. These were followed, after further instructions and alteration of head position, with 32 transfer trials employing another random permutation of the cards. Details of general procedure not specified here were as in the Attneave and Olson (1967, Exp. I and II) study.

The Ss were assigned to four groups defined by two conditions of transfer, each with an experimental (E) and a control (C) group. The difference between E and C groups was simply that the former were instructed to adopt a particular (head-anchored) frame of reference in viewing the stimuli, either initially or during the transfer trials. The present control groups, 1C and 2C, were very nearly replications of the groups called 5 and 2, respectively, in the Attneave and Olson (1967) study.

Under Cond. 1, *S*s viewed the stimuli initially (i.e., during instructions, preliminary practice, and the first 64 DRT trials) with their heads tilted 45° clockwise. They were all then shifted to a head-upright position for the 32 transfer trials. After this shift, they were required to give the same responses to the same *retinal* stimuli. In the case of Group 1E, the critical part of the initial instructions was as follows:

> When your head is tilted, there are two ways you can think of "up" and "down": you can think of the ceiling as "up" and the floor as "down," or you can think of the top of your head as "up" and your chin as "down." Now, as you look at these lines, I want you to think of "up" and "down" the second way: always think of the top of your head as "up."

This idea was repeated in several different paraphrasings, and its importance to the experiment was emphasized. When *S* was first told the names of the slants, the four cards on which the lines appeared contained the words TOP and BOTTOM rotated 45°, i.e., at the *retinal* top and bottom of the field. No subsequent cards contained these words. No attempt was made to influence the frame of reference of the 1C group, with the exception that the words TOP and BOTTOM were shown, without comment, at the *gravitational* top and bottom of the initial four cards. Thus the TOP-BOTTOM labels merely reinforced the natural tendencies of control *S*s (cf. Group 5 of the Attneave and Olson study), whereas they constituted a part of the general effort to induce a head-oriented frame of reference in the experimental *S*s.

At the time of transfer, the new assignment of names to slants was illustrated by saying "It's just as if you were reading and rotated your head and rotated the book at the same time." Samples were shown, and care was taken to insure that every *S* understood the principle involved.

It should now be evident to the reader that *if* people are able voluntarily to rotate the frame of reference for orientation in a functionally meaningful way, the experimental instructions should have the effect of improving transfer performance.

Condition 2 consisted of training with head upright and transfer with head tilted 45°; during the latter *S* was again required to give the same names to the same retinal slants. During the preliminary and training trials *S*s in Group 2C and Group 2E were treated identically, and like those in Group 1C except that the words TOP and BOTTOM did not appear at all on the initial instructional cards. In the case of Group 2E only, instructions were designed to influence *S*'s frame of reference *at the time of transfer.* After being given the control instructions, *S* was urged to think of the top of his head as up, etc., and assured that if he did so his identifications would be correct. The four cards bearing the words TOP and BOTTOM rotated 45° were used to illustrate assignment of names to slants under the transfer task. The transfer instructions for Group 2C were like those used under Cond. 1 except for minor changes relating to direction of shift. With this group the TOP-BOTTOM labels were never used, since presenting them in the gravitational orientation at the time of transfer would have been in rather obvious contradiction to the transfer instructions. The aim was essentially to let control *S*s handle the transfer task however they would, with no special help or hindrance. Control *S*s, it should be emphasized, understood the requirements of the transfer task (and made practically no errors on it); they understood the principle that the lines were being rotated along with the head, but any direct suggestion that they should think of up, down, etc., in any particular way was avoided.

RESULTS

Under Cond. 1 (see the left graph in Fig. 1), the effect of the experimental instructions was strikingly positive. Whereas control *S*s were markedly slowed down (as in the Attneave and Olson, 1967, study) when shifted from head tilted to head upright and required to give the same names for the same retinal slants, experimental *S*s, who had presumably viewed the lines in terms of a head-anchored frame of reference from the beginning, showed no mean decrement but rather a continuing improvement. This difference between Groups 1C and 1E is highly reliable, t (30) = .448/.094 =

4.76, $p < .001$. Here and in the subsequent test, the difference referred to is between two distributions of differences, the latter being between DRT, averaged within each *S*, on the second 32 training trials (i.e., Blocks 5–8 of the graph) and corresponding DRT on the 32 transfer trials.

Results under Cond. 2 (Fig. 1, right graph) show a facilitating effect of rotating the reference system with the head at the time of the retrieval of associates. This effect is quite substantial, though smaller than that of Cond. 1, t (30) = .254/.081 = 3.14, $p < .01$.

Reaction times from the 64 pretransfer trials of Cond. 1 were separately averaged for diagonal stimuli and for horizontal and vertical stimuli (gravitationally defined) within each *S*. The differences between these means (diagonals minus H-V) are plotted on the abscissa of Fig. 2 for all *S*s, with different symbols for experimentals and controls. On the ordinate is plotted each *S*'s "transfer loss,"[2] i.e., the increase in his DRT (averaged over all slants) from the last 32 pretransfer trials to the 32 posttransfer trials.

The expectations with which we examine this graph are somewhat as follows: (*a*) that control *S*s will respond faster to (physical) horizontals and verticals than to diagonals despite their head tilt (as in the Attneave and Olson study) and show high transfer losses; (*b*) that experimental *S*s will respond

[2] This term is not to be taken too literally. Negative values of "transfer loss" do not mean that altering the head position improved performance; a more likely interpretation is that performance continued to improve with practice despite the change.

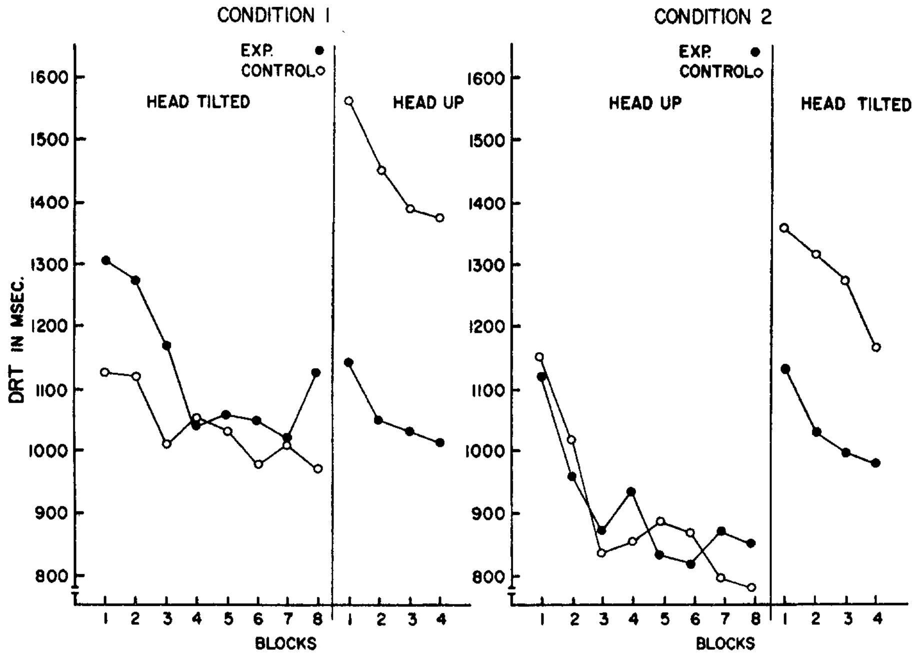

FIG. 1. Performance curves, pre- and posttransfer, of experimental and control groups under the two conditions. (Each point represents a block of eight consecutive trials. A vertical line marks the beginning of the transfer task under each condition.)

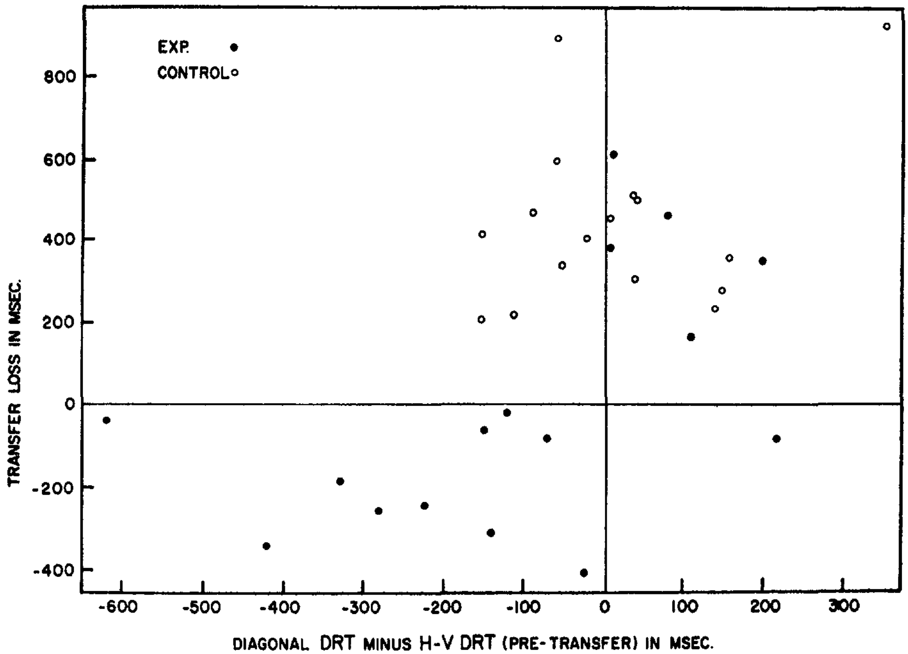

FIG. 2. Relationship between two response variables under Cond. 1. (Each point represents an *S*. It is hypothesized that both variables are dependent on *S*'s frame of reference.)

faster to diagonals which are vertical and horizontal relative to their heads and assumed frames of reference and show low transfer losses; (*c*) that if some control *S*s happen to adopt a head-oriented frame of reference on their own initiative, this deviation from the group will be reflected in decreased scores on *both* variables; (*d*) likewise, that if some experimental *S*s are unwilling or unable to adopt a head-anchored frame of reference, their scores will be relatively high on both variables; and (*e*) that, as a result of all the preceding factors, the two variables will be positively correlated.

These expectations are partially confirmed. We have already seen that transfer loss is significantly greater for Group 1C than for Group 1E; on the other variable (diagonal DRT minus H-V DRT) the difference is not significant at a convincing level, t (30) = 1.87, $.05 < p < .1$. However, the correlation between the two variables is quite significant, albeit modest. Pooling groups, one finds $r = .53$, $p < .001$. For Group 1E alone, $r = .51$, $p < .05$; for Group 1C alone, $r = .31$ which is not significant.

It is somewhat surprising that Group 1C shows a 50–50 split on the slant variable, half of the *S*s being faster on diagonals, the other half on horizontals and verticals. The authors have no good reason to suppose that this represents anything but a sampling difference from the more extensive results of Attneave and Olson (1967), who found lower DRTs to (physical) verticals and horizontals under similar conditions. Group 1E, on the other hand, is faster on diagonals (retinal horizontals and verticals), but not quite significantly so, t (15) = 1.92, $.05 < p < .1$.

Discussion

The results obtained strongly support the system of hypotheses set forth in the introduction. Optimal transfer occurs when there is an invariant relationship between naming response and *perceived* slant, from one situation to another. Perceived (phenomenal, subjective) slant is slant relative to a prevailing descriptive or reference system. The mapping of receptor inputs on to this system is variable; the system may be "rotated" relative to the input. Under normal conditions, as in the Attneave and Olson study or in the present control groups, the rotation is such as to achieve "constancy," i.e., perceived slant equivalent to physical slant, and it occurs without conscious intervention on the part of the observer. The reference system is subject to voluntary control, however, at least to the extent that it can be maintained in constant relationship to the axes of the head. (This is not to say that more drastic forms of control are not possible.)

The authors are well aware that the foregoing discussion is composed mainly of assertions about unobservable mediating variables (orientation of reference system and perceived or phenomenal slant). If there is any possibility of understanding or describing economically the present results without recourse to such variables, we are entirely unable to see it. The conclusion that phenomenal orientation (rather than either retinal or physical orientation) is the critical antecedent of identifying behavior is entirely in agreement with the conclusion of Rock (1956) and Rock and Heimer (1957) from related studies. Moreover, Rock and Leaman (1963) have shown quite convincingly that a voluntarily assumed vertical, which need not be coincident with either the retinal or the gravitational vertical, may serve as the crucial determinant of perceived symmetry and the consequent effect of symmetry on similarity judgments.

One can infer, with a little more caution, that lines *perceived as* horizontal and vertical (for whatever reason) are identified faster than lines perceived as diagonals. If this effect were not located at the phenomenal level, at least in part, there would be no basis for the significant correlation shown in Fig. 2, i.e., for the limited predictability of transfer loss from differential performance on diagonals vs. horizontals and verticals before transfer. Some features of Fig. 2 are mildly puzzling, however. It is not obvious why, in the region between −200 and 0 on the abscissa, there is a perfect vertical separation between the five experimental points and the eight control points. An effect somewhat like this is to be expected if abscissa values contain more random error than ordinate values, i.e., if the transfer-loss variable is more closely related to an underlying frame of reference than is the slant-difference variable. As a limiting case, imagine all the points representing *S*s with one frame of reference in one tight cluster, and all the points representing *S*s with the other frame of reference in another tight cluster to the upper right, then introduce a great deal of random variation on X and somewhat less on Y. The best guess, in accord with this interpretation, is that the five *S*s of Group 1E who show a positive transfer loss employed a gravity-oriented frame of reference despite instructions to the contrary, and differ only randomly from controls.

The results of Attneave and Olson (1967) did not rule out the possibility that horizontals and verticals are processed more quickly than diagonals at the projection level *as well as* at the phenomenal level, in which case the two effects might combine either additively (with head upright) or subtractively (with head tilted). The likelihood of this possibility is increased by the fact that our present Group 1C responded no faster to one slant than to another. Some interesting alternative hypotheses remain tenable, however. Suppose, e.g., that a control *S* employed a *dual* frame of reference and classified the four lines as (*a*) physically vertical, (*b*) physically horizontal, (*c*) retinally vertical, or parallel to the major axis of the head, and (*d*) retinally horizontal, or parallel to a line joining the eyes. By this system he might well identify the four slants with equal speed before transfer, but perform poorly on the transfer task with head upright.

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