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DISCRIMINABILITY OF STIMULI VARYING IN PHYSICAL AND RETINAL ORIENTATION[1]

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In 2 discrimination reaction-time experiments, adult human Ss responded faster to horizontal and vertical stimuli (lines or rectangles) than to stimuli tilted 45° right and left. When S viewed the stimuli with his head tilted 45°, so that physical and retinal orientation were in opposition, it was on the physical rather than the retinal horizontals and verticals that performance was superior. In another experiment head position was changed 45° after a period of learning. Ss required to give the same responses to the same physical orientations did much better on the transfer task than those required to give the same responses to the same retinal orientations. The latter were not significantly superior to a pure transposition group for whom the S-R relationships were shifted both physically and retinally.

The octopus discriminates easily between a horizontal and a vertical rectangle, but not between two oblique rectangles that also differ by 90° (Sutherland, 1957, 1958, 1960). Very similar results are obtained with preschool children (Rudel & Teuber, 1963); also with goldfish (Mackintosh & Sutherland, 1963). In the cat, however (Sutherland, 1963), no such difference is found, and Sutherland remarks in passing that the oblique stimuli seemed less confusable to the cats than to him. The most obvious explanation of these behavioral results is in terms of receptive field configurations, particularly since Young (1962) has observed that dendritic trees in the visual system of the octopus show proliferation most often in vertical and horizontal directions, and since Hubel and Wiesel (1959) have found that slope analyzers in the cat's visual cortex are about evenly distributed over all orientations. One is tempted to suppose, from the behavioral evidence, that man's primary visual system contains a preponderance of vertical and horizontal analyzers. However, no converging anatomical or physiological evidence exists at the human level at

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present, and the results reported here tend in fact to discourage this hypothesis in any simple form.

We asked the following questions: (*a*) In a discrimination reaction-time task, will human adults identify horizontal and vertical stimuli (lines or rectangles) more quickly than oblique ones? (Exp. I and III). It is well known that DRT increases as stimuli become more similar or confusable. (*b*) If so, is the effect dependent on the *physical* or the *retinal* orientation of the stimuli? (Exp. I and III). This was determined by running some *S*s with heads tilted 45°. (*c*) When people learn to identify slants, is it to the physical or to the retinal orientation that a response becomes attached? (Exp. II). This was determined by a transfer study.

Experiments I and II are conceptually discrete, but involve the same *S*s and overlapping data. Experiments I and III are conceptually similar, but differ in *S*s, method, and materials.

EXPERIMENT I

Method

Subjects.—The *S*s were 48 paid University of Oregon undergraduate volunteers, 30 females and 18 males between the ages of 18 and 25 yr. It was required that acuity of the right eye be 2/2 or better, as measured by a suitably reduced Snellen chart in the tachistoscope, and that response to a Lancaster-Regan figure show no suggestion of astigmatism.

Materials.—Stimuli were black lines, .21 in. long (.5° visual angle) × .02 in. wide, drawn on white detail paper which in turn was mounted on cardboard. Four orientations were used: horizontal, vertical, and two 45° diagonals. The center of each line was .84 in. (2°) from a central fixation point, which appeared only in the preexposure field as a black dot .1 in. in diameter on a white ground. Each slant was drawn, on separate cards, in eight different directions (above, upper right ... etc.) from the fixation point, making 32 cards in all. The reason for this variation was to avoid associating a given slant with unique retinal elements.

Practice stimuli were drawn in equally spaced positions around the edge of a circular white paper disk, which was fastened to a wall. The order was random, with each orientation appearing 11 times.

Apparatus.—A Gerbrands two-field tachistoscope was fitted with a rotatable head piece which held *S*'s head in an upright or 45° right position. The head piece blocked light from outside the tachistoscope, and allowed viewing with the right eye only. Both preexposure and stimulus fields were masked to a circular area 7 in. in diameter, 2 ft. from *S*. The (ground) luminance of both fields was 7½ mL. No other contours were visible inside the tachistoscope.

A hand switch held by *S* triggered the stimulus field for a 1/10-sec. exposure and also started a clock. The output from a microphone taped to *S*'s throat was led to a voice relay which shut off the clock.

Procedure.—The *S* was told that the purpose of the experiment was to study his reaction time under several different conditions. No other statement about the nature of the study was made.

After being tested for acuity and astigmatism, *S* was told that on each trial he would look into the tachistoscope, keeping his head fitted snugly into the head piece, 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 following its exposure. After this general orientation, he was shown the stimuli and told their respective names. He then practiced responding with these names to the stimuli arranged around the circle on the wall; incorrect responses were promptly corrected. Two cycles of the circular array constituted the preliminary training session.

The four names used were *Adam, Abner, Albert,* and *Andrew.* Assignment of these to line orientations was completely counterbalanced (in the Latin-square manner) over *S*s within each group (also within each of the small groups into which *S*s were divided in Exp. II). The idea of using manual rather than verbal responses was considered but rejected because almost any motor response is likely to have some relationship of compatibility or incompatibility with a line of a given slant.

The 48 *S*s were divided into two groups of 24. Group U viewed the stimuli with their heads upright; Group T viewed them with heads tilted 45° clockwise, in the preliminary session as well as in the experiment proper. Thus, for Group T, the *physically* oblique lines were *retinally* horizontal and vertical, and vice versa.

In the final instructions, *S* was told to press the button each time *E* gave a "ready" signal, and respond with the appropriate name as quickly as possible, without making mistakes. (Whenever an error was made, *S* was reprimanded, and the trial was repeated a little later in the series.) The *S* was allowed to sit back from the viewing position between trials and rest if he wished, but in practice he rarely did so. The surround of the head piece was a homogeneous screen the illumination of which was roughly matched to that of the tachistoscope fields. Between trials *E* changed stimuli, gave the "ready" signal, checked the correctness of the response, and recorded the reaction time: those operations made for an intertrial interval of about 20 sec. Two series of the 32 stimuli were presented for a total of 64 trials. Order was randomly permuted within each series.

Results

DRTs obtained under the different conditions are shown in Table 1. The terms *horizontal, vertical,* and *oblique* refer to physical rather than retinal orientation. Classification in terms of retinal orientation would have been equally legitimate; because of this basic ambiguity *t* tests on the results are rather more comprehensible than *F* tests would be. For Group U, reactions to horizontals and verticals are faster than to obliques by a small (72 msec.) but significant amount, $t\ (23) = 2.94$, $p < .01$. For Group T, the corresponding difference (re physical orientation) is 56 msec., which is just short of the .05 confidence level, $t\ (23) = 1.95$. The difference between these two differences (72 vs. 56 msec.) is quite insignificant, $t\ (46) = .43$. Note, however, that if we compare slants of equivalent *retinal* orientation, the sign of the 56-msec. difference for Group T

TABLE 1

MEAN DRTs IN MSEC., EXP. I

Stimuli (re physical axes)	Head Upright	Head Tilted
Obliques	1019	1129
Horizontals & Verticals	947	1073
Difference	72	56
Mean (all Slants)	983	1101

becomes negative, and the difference between differences (72 vs. −56 msec.) becomes highly significant, $t\ (46) = 3.39$, $p < .01$. These results clearly support the conclusion that discriminability is dependent on physical rather than retinal orientation, though the possibility that retinal orientation makes *some* difference is not disproved.

For unknown reasons (which might have to do merely with fatigue, annoyance, etc.) performance of Group T was generally poorer than that of Group U: the difference between overall means (983 and 1,101 msec.) is significant at the .05 level, $t\ (46) = 2.18$.

EXPERIMENT II

We now ask: if an *S* learns to respond differentially to slants with his head in a given orientation, as in Exp. I, and his head position is then changed (from upright to 45° tilt, or vice versa), will he find it easier to give the old responses to stimuli with the same physical orientation, or to stimuli with the same retinal orientation? A transfer study of this sort, in which the entire procedure of Exp. I became the "original learning" portion, was conducted with the same *S*s.

Procedure.—Immediately after the 64 DRT trials described earlier, *S* was given new instructions dependent on the transfer group to which he was assigned. Group U was divided into Transfer Groups 1, 2, and 3 of eight *S*s each, likewise Group T into Transfer Groups 4, 5, and 6. The division was such as to preserve counterbalancing of names over slants within each transfer group.

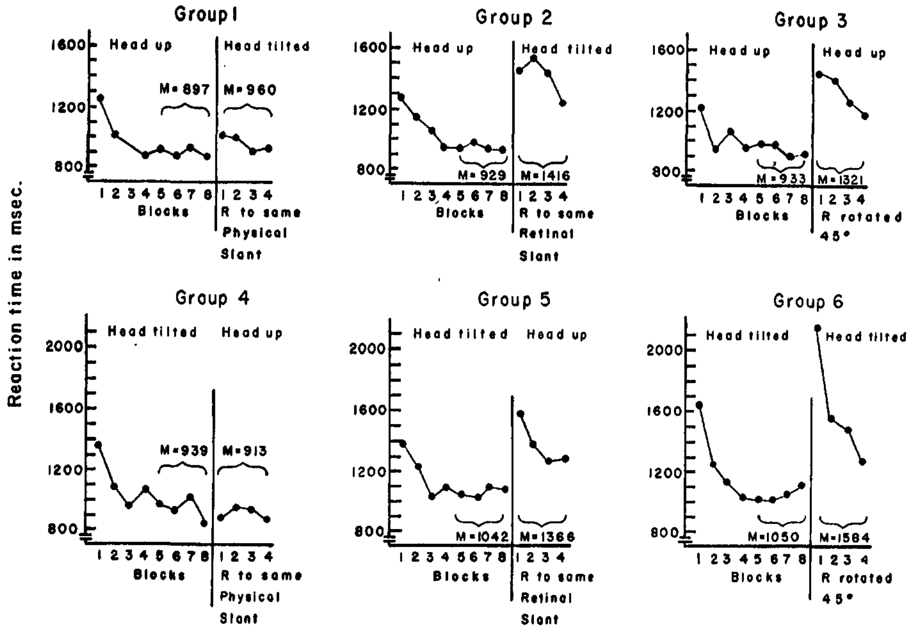

Fig. 1. Performance curves, pre- and posttransfer, for the six groups of Exp. II. (Each point is the mean of 8 consecutive trials. Numerical means are given for the 32 transfer trials and for the 32 trials immediately preceding transfer.)

In Groups 1 and 2, *S*'s head position was shifted from upright to tilt (45° clockwise); symmetrically Groups 4 and 5 were shifted from tilt to upright. In Groups 1 and 4 *S*s were told that they would use the same names they had been using for lines that were physically or objectively the same, "just as if you rotated your head while reading without rotating the book." The *S*s in Groups 2 and 5 were told to use the same names they had been using for lines that were in the same relation to their heads, "just as if you rotated your head while reading and rotated the book at the same time." For Groups 3 and 6 the transfer task was one of pure transposition: They maintained the same head position as in Exp. I, but the names were rotated 45° clockwise for the upright group (3) and 45° counterclockwise for the tilt group (6): "It's just as if you were reading and rotated the book without rotating your head." In all groups the new assignments of names to slants were demonstrated in detail, and *S*'s understanding of the changes was tested in part by having him name the first four lines on the practice disk. If his grasp of the transfer task seemed at all dubious, he was instructed further until it was clear that he understood the principle involved.

Each group was then run through a complete series of 32 randomly ordered trials (each stimulus card presented once) under the new conditions.

At the end of Exp. II, *S* was asked what he had come to think of as "up" in the new situation, in an attempt to determine whether any such shift in frame of reference had occurred.

Results

Figure 1 shows performance of each group under original (Exp. I) and altered (Exp. II) conditions. The points plotted are means for blocks of eight consecutive trials, with all slants combined. Transfer performance was compared with that on the second half only of the pretransfer trials; note that the learning curves in this region are very nearly asymptotic.

On the whole, these results present a fairly clear and coherent picture. When the same responses are attached to the same physical orientations, but to different retinal orientations (Groups 1 and 4), little or no performance decrement occurs. When the same responses are attached to the same retinal orientations but to different physical orientations (Groups 2 and 5), performance is markedly disrupted, much as it is in a pure transposition task (Groups 3 and 6), in which physical and retinal orientation are both changed.

An exhaustive evaluation of the results involves so many comparisons that we found it necessary to do several separate analyses of variance on the data. Since it seems unjustifiable to burden the reader with the details of these, we shall report only those outcomes for which some minimal interest or importance is evident.

The change in conditions produced no significant performance decrement in Groups 1 and 4; F (1, 14) = .3. The decrement is highly significant in Groups 2 and 5; F (1, 14) = 27.4, $p < .001$, and in Groups 3 and 6, F (1, 14) = 40.6, $p < .001$. In each of these analyses head position (or direction of change in head position, i.e., the difference between the two paired groups) constituted a second classification: in no case did this variable produce significant differences, either as a main effect or in interaction (all p's > .1). It may be pointed out that the latter tests are less powerful than the former, since they involve comparisons between rather than within *S*s.

A further analysis on within-*S* difference scores shows, as one might expect from the foregoing, that the decrement in Groups 2 and 5 is greater than in Groups 1 and 4: F (1, 28) = 24.54, $p < .001$.

Finally, we sought to determine whether the holding constant of retinal orientation provided an advantage over pure transposition. Groups 2 and 5 turn out not to differ significantly from Groups 3 and 6 with respect to within-*S* difference scores: F (1, 28) = .315. This was a two-way analysis of variance with the groups paired, somewhat arbitrarily, as in Fig. 1. If effects of absolute head position had caused differences to be increased in Group 2 and decreased in Group 5, this effect would have appeared in the interaction term. Actually the interaction was nonsignificant: F (1, 28) = 2.45, $p > .1$.

Answers to the question at the end of the experiment, "What did you think of as 'up'?" generally referred to the physical vertical. Only three *S*s indicated that they rotated their field orientations in the transfer task. These were all in Group 2, and their DRTs under the transfer condition were by far the lowest in that group. They showed a mean decrement of 131 msec., whereas the remaining five *S*s in Group II showed a mean decrement of 701 msec.

Experiment III

The differences in DRT attributable to slant in Exp. I were rather small (about 7½%), even with head upright. We wondered if the method (all four slants discriminated in the same series) might have been less than optimal for revealing slant effects. Another possibility considered was that all the lines used were pressing some asymptote of discriminability. We decided therefore to vary both method and materials in a new experiment. A two rather than four choice DRT paradigm was used (horizontal vs. vertical, or left oblique vs. right oblique); and 3:2 rectangles were used as well as lines (which may themselves be considered roughly 10:1 rectangles).

Method

Subjects.—Forty-eight new *S*s were employed, 22 men and 26 women. They were screened for acuity defects and astigmatism as in Exp. I.

Materials.—The 32 stimulus cards of Exp. I (q.v.) constituted half the materials. An additional 32 cards were constructed by exactly the same plan, but the lines were replaced with 9/40 in. × 6/40 in. rectangles cut from black paper. These were very slightly longer than the lines, which subtended half a degree of visual arc in the tachistoscope.

The 3:2 proportion was chosen with the aim of providing stimuli that would take longer to discriminate with respect to orientation than the 10:1 lines, but that could still be discriminated with practically no error. Pilot work indicated that rectangles only a little plumper than 3:2 would not meet the no-error criterion, presumably because of acuity limitations: i.e., *S* sometimes reported that he simply could not "see" the orientation of the rectangle.

Apparatus.—The tachistoscope used in Exp. I.

Procedure.—Half of the *S*s discriminated lines, the other half rectangles. Orthogonally, half viewed the stimuli with heads upright, the other half with heads tilted 45° clockwise. The *S* was given a total of 128 trials, in 8 blocks of 16. Within each subgroup, half the *S*s discriminated between horizontal and vertical orientations during odd blocks and between right oblique and left oblique during even blocks; for the other half this assignment was reversed. Within any given block of 16 trials, order of the 16 cards displaying horizontals and verticals, or on alternate blocks the 16 obliques, was randomly permuted.

The *S*'s alternative responses were always the two vowel sounds "o" and "e," which operated a voice key as before. Assignment of responses to stimuli was balanced within subgroups, though with a relational invariance that will be mentioned later.

The simplicity of the task was such that no extended pretraining was necessary; *S* was merely shown the stimuli in the tachistoscope and told the response to give to each. He was reminded of the correct responses at the beginning of each block.

Aspects of procedure not explicitly described in this section were as in Exp. I.

TABLE 2

MEAN DRTs IN MSEC., EXP. III

Stimuli (re physical axes)		Head Upright		Head Tilted	
Obliques	Lines	591	628	592	645
	Rects.	664		698	
Horizontals & Verticals	Lines	549	584	573	625
	Rects.	619		676	
Differences	Lines	43	44	19	21
	Rects.	45		22	
Means (all Slants)	Lines	570	606	583	635
	Rects.	642		687	

TABLE 3

SUMMARY OF ANALYSIS OF VARIANCE, EXP. III

Source	*df*	*MS*	*F*
Between *S*	47		
A (Materials)	1	1853.44	6.462*
B (Head tilt)	1	200.25	<1
AB	1	64.88	<1
S w. Groups (Error, b.)	44	286.81	
Within *S*s	48		
C (Slant)	1	248.75	23.578***
AC	1	.06	<1
BC	1	33.03	3.131
ABC	1	.25	<1
C×*S* w. Groups (Error, w.)	44	10.55	

* $p < .05$.
*** $p < .001$.

Results

The average DRTs obtained are shown in Table 2, and most but not all questions of significance are covered by an analysis of variance summarized in Table 3.

The rectangles take somewhat (about 15%) longer to discriminate than the lines; not as much longer as we had hoped in designing the experiment. Otherwise, results with the two types of materials are so closely parallel that they need not be considered separately.

The main effect for slant is significant at the .001 level. More important, Group T *S*s, considered separately, respond significantly faster to physical horizontals and verticals (i.e., retinal obliques) than to physical obliques (i.e., retinal horizontals and verticals): $t = 2.91$, $p < .01$. (In Exp. I this difference was just short of the .05 level. Differences attributable to slant are consistently smaller—either in milliseconds or as proportions of total DRT—in Exp. III than in Exp. I, but more significant because of reduced error.)

Consideration of the mean differences in Table 2 suggests that the advantage of the (physical) horizontals and verticals over the obliques was about twice as great for Group U as for Group T, i.e., that retinal orientation is of some importance.[2] However, the difference attributable to retinal slant (44 vs. 21 msec.) is of very dubious reliability: note F_{BC}, for which $.05 < p < .1$.

If we turn the classification about and ask how the differences between *retinal* orientations are affected by head position, we are in effect comparing a 44 msec. difference with a negative 21 msec. difference (cf. the similar comparison in Exp. I). This difference is highly significant: $F(1, 44) = 23.5$, $p < .001$.

[2] Inspection of the differences in Table 2 tends to give one more subjective confidence than is warranted in the reliability of retinal orientation effects, because of the close agreement of results between materials. This agreement is far greater than we have any right to expect on the basis of within-subgroup variability: note that the Fs for interaction with materials (AC and ABC, Table 3) are much less than one. We checked carefully the computation of these suspiciously low interaction terms and verified their accuracy. We then considered the possibility that the error term was artificially inflated by within-group counterbalancing (of block order and S-R pairing). Calculation of a new error term with the counterbalanced variables (which were perfectly confounded with each other) held constant made virtually no difference, however. The only conclusion remaining is that the minuteness of these interaction terms is due to chance.

Discussion

People identify the orientation of horizontal and vertical objects more quickly—though not a great deal more quickly, in absolute terms—than that of oblique objects. By far the major portion of this effect, if not all of it, must be ascribed to physical rather than retinal orientation. This is to say that the perceptual system makes allowance or correction for head position, on the basis of proprioceptive information, before the effect occurs. (In the present experiments the corrective information must have come from the labyrinths, muscles, or joints, or else from some purely cognitive level, since the eye was presented merely with a circular field regardless of head position.) If one undertakes to explain this effect in terms of receptive field orientations, he must suppose that the analyzers in question are located in a part of the visual system that is tied to the retina in a labile manner.

The evidence supporting a retinal-orientation effect is exceedingly weak ($p < .1$), and is confined almost entirely to Exp. III. For the sake of argument, however, let us entertain the possibility that retinal orientation did make a small difference. Orientation of low-level receptive fields might be responsible, but other plausible hypotheses also exist. Suppose that the phenomenal vertical and horizontal (we use the term *phenomenal* for want of a better one) are more easily discriminated than the phenomenal obliques. Suppose further that the phenomenal reference axes are normally the same as the physical, but that people have some limited ability to adjust or rotate them into correspondence with the axes of the (tilted) head, when there is some advantage of doing so. (At least three *S*s in Exp. II seem probably to have done this.) If an *S* with tilted head in Exp. III could have voluntarily tilted his reference axes into correspondence with the axes of his head on alternate blocks of trials, he would have had the advantage of always dealing with phenomenal verticals and horizontals. (Note that this argument does not apply to the four-choice situation of Exp. I, in which practically no evidence for the importance of retinal orientation was found.) The advantage for an *S* using this strategy would have been further enhanced by the fact that he could always have used the same response for the same phenomenal slant, since by an accident of counterbalancing the same response ("o" or "e") was common to the vertical and right oblique, for all Group T *S*s.

The possible influence of retinal or even optical effects cannot be excluded, however. It has been found repeatedly that visual resolution is best for horizontal and vertical test objects (Higgins & Stultz, 1948, 1949; Leibowitz, 1953; Ogilvie & Taylor, 1958; Taylor, 1963). Informal observation indicates that this effect depends on retinal orientation: according to Higgins and Stultz (1948) "the perceptibility of the diagonal lines was improved, and the perceptibility of horizontal and vertical lines diminished when the observer merely tilted his head."

In the case of other studies that have shown superior discrimination in vertical and horizontal regions—e.g., the experiment of Leibowitz, Myers, and Grant (1955) on estimation of radial location—it is an open question whether physical or retinal orientation is the important variable. These studies, and certainly the one of Rudel and Teuber cited earlier, might profitably be repeated with a head-tilt condition.

Experiment II shows clearly enough that responses are normally attached to physical rather than retinal orientations, i.e., that the perceptual machinery makes correction for head position before associations are formed (Groups 4 and 5) or retrieved (Groups 1 and 2). These results are in general agreement with those of Rock (1956) and Rock and Heimer (1957), whose *S*s attempted, under several conditions of head tilt, to identify tachistoscopically presented complex objects that were either upright physically or upright on the retina. The physically (or "phenomenally") upright objects were clearly the easier.

Special attention is due the three *S*s in Group 2 who reported rotating the frame of reference with the head, and who performed dramatically better than their group mates under the transfer condition. Either these *S*s are exceptions to the rule that associations are attached to physical rather than retinal orientations, or else they were able voluntarily to adopt a retinal frame of reference when it became useful to do so. If the former hypothesis is true, why did not similar *S*s appear in Groups 1 and 4, where they would have shown very poor transfer? If the latter, why did not similar *S*s appear in Group 6, where rotation would have been equally advantageous? (In Group 5, voluntary adoption of a retinal frame of reference would have had to occur during the pretransfer trials, when *S* had no way of knowing that it could aid his later performance. In Group 3, *S* would have had to rotate to an arbitrary frame of reference, neither physical nor retinal.) About equally puzzling is the fact that the remaining five *S*s in Group 2 showed poorer transfer than any other group.

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