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The effect of landmark features on mental rotation times

JULIAN HOCHBERG and LEON GELLMAN
Columbia University, New York, New York 10027

By varying what we take to be the saliency of *landmarks* (which are cues to location and orientation that are unique and visible from a distance), the slopes and intercepts of the time/angle function in the "mental rotation" task were caused to vary accordingly.

As the angle between orientations of two shapes is increased, subjects who have been trained in "mental rotation" take longer to decide that the shapes are the same and not mirror images of each other (Cooper, 1975; Cooper & Shepard, 1973; Shepard & Metzler, 1971). Because Shepard and his colleagues have found that the time/angle function is always monotonic and often remarkably linear for a variety of tasks and circumstances, they argue that the task is performed by means of an underlying "analog" process, proceeding at a rate of approximately 60 deg/sec (Shepard & Metzler, 1971).

Just and Carpenter (Note 1) have shown that subjects make more eye movements to compare corresponding points in the two shapes as the angular difference between their orientations increases, which may be due to the increased difficulty of localizing and identifying those points when the shapes differ in orientation. Whether or not "mental rotation" is in some sense isomorphic to an objective rotation of the stimulus object, therefore, Shepard's procedure may be a good tool with which to study certain questions: How do we know where to direct the successive glances by which we sample the objects and scenes in the world around us? How do we know the location of the detailed information that we acquire by those glances?

Following the system devised by Lynch (1960) for describing the idea of a city's shape that is held by its inhabitants, unique features that are visible at a distance and that provide information about location and orientation will be called "landmarks." Lynch's term is clearly applicable to the perceptual encoding of objects as well as of cities. In a shape that is complex in the sense that it has a number of similar parts or regions whose differences cannot be apprehended in a single glance, a landmark is a feature that serves to distinguish the parts. With objects that extend well beyond the fovea, a landmark feature must be identifiable at a distance, that is, identifiable by peripheral vision. Intuitively, the term seems to reflect an important aspect of form perception. To vary such landmark features and to study their effects, however, we need a task that is affected by their presence and characteristics. The mental rotation task seems ideally suited to that purpose: The subject must decide whether or not two shapes are the same and, when their orientations differ, he cannot identify their corresponding parts simply by their locations in his visual field. In fact, city maps, which often make formal and explicit use of landmarks, usually require some degree of mental rotation by their users.

Can we use the mental rotation task to define and measure landmark features? It is possible that the task is insensitive to differences between stimulus patterns: Cooper (1975) recently reported that no differences were obtained in mental rotation times as a function of shape complexity. Her patterns, however, were constructed according to random decisions, and there is no necessarily close connection between those definitions of complexity and the matter of landmark accessibility with which we are concerned here. To be useful in the mental rotation task, a landmark feature must either provide direct information about orientation, even when it falls in peripheral vision, or must indicate where the subject will find such information by directing his fovea to the landmark's vicinity.

The patterns shown in Figure 1 were designed with these requirements in mind. In Shape E, the cue to orientation is unique and peripherally visible. In two other shapes, C and D, redundant and irrelevant features (the latter being identical in the shape and in its mirror image) were added. These elements were added so that they would mask each other when viewed peripherally (Bouma & Andriesson, 1973; Woodworth, 1938, p. 739); because the terminal element is only partially masked, an uninformative "T" is used in that site. In the case of Shapes C and D, however, the clump of features identifies the only region at which the subject need look in order to obtain directional information and, in foveal or near-foveal vision, the informative features would not be masked by the uninformative ones. In the two remaining shapes, A and B, the sets of features or details are sufficiently far from each other that the subject would not be expected to resolve the details and their spatial order properly and, therefore, would not know on the basis of peripheral information

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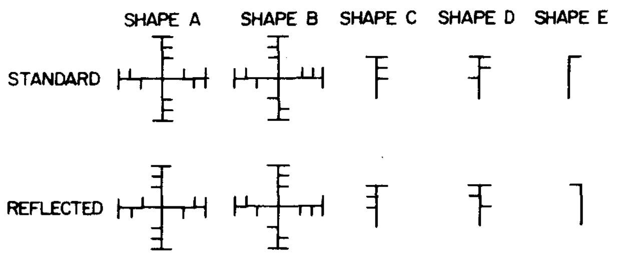

Figure 1. Stimulus shapes in standard and reflected form.

alone whether the two examples were the same, nor where to look in order to compare their corresponding parts.

Shapes A and B provide directional information by the same features as do C and D, but in the former pair those features cannot serve well as landmarks because they are not unique (nor directionally informative) in peripheral viewing, and the subject cannot identify them as such without additional search.

We have thus constructed stimuli which will, hopefully, differ in their accessibility of landmark features. We would expect these differences to be reflected in the intercepts and, perhaps, the slopes of the mental rotation function as well, for the following reason: When the subject can tell in his first glance whether the patterns are same or mirror image, or precisely where he must look in order to find a specific part of a pattern, his original search time will be decreased; to the degree that the increase in decision time with an increase in angle is a function of the additional comparisons that have to be made, landmarks should depress the slope of the function by increasing the efficiency of the comparison process.

The mental rotation function should therefore serve to measure the accessibility of landmark features as we have described them. The stimuli in Figure 1 differ from each other in additional ways, of course, which may be responsible for (or contribute to) whatever differences we obtain. But our first task is to determine whether the mental rotation functions differ for these stimuli as expected.

METHOD

Subjects

Three subjects, all undergraduates at Columbia University, were each paid $3.50/h for three 1-h experimental sessions. The subjects (one male, two female) were all right-handed. None had previously participated in a mental rotation experiment.

Stimuli

The stimuli consisted of the five pairs of line drawings shown in Figure 1. Each drawing was mounted on a disk whose perimeter was divided in 18 20-deg steps from 1 to 340 deg. Using a format similar to that of Shepard and Metzler (1971), each stimulus presentation consisted of two disks with either the same shape on both disks or different shapes (a pattern and its mirror image) on the two disks. The left shape was rotated to some multiple of 20 deg, the right shape was set at 0, 40, 80, 120, or 160 deg clockwise, according to a predetermined random order, and the pair was photographed on high-contrast 16-mm film. In all, there were six "same" and six "different" trials for each of the five levels of angular difference in orientation, for each of the five stimulus shapes, making a total of 300 trials per session. The different shapes were then spliced together in blocks so that the final stimulus film contained seven to nine trials per shape, intermixed with the other shapes in random blocks.

When presented to the subject, each shape appeared as a set of white lines on a black disk, the pair of disks being surrounded by a gray field of 343 cd/m^2 L. The interstimulus field was also white. The stimuli subtended visual angles of 3 x 1 deg for Shape E, 3 x 1.67 deg for Shapes C and D, and 6.33 x 6.33 deg for Shapes A and B. All sets were inscribed in disks of 10.67 deg, separated by 2 deg.

Apparatus

The stimuli were projected in photographic negative by a single-frame 16-mm projector to a rear-projection screen 19 in. in front of the subject. A switch permitted the experimenter to advance the projector one frame and start a timer. Before him, the subject had two reaction time keys, 12 in. apart, which would signal his decision and stop the clock.

Procedure

During the preexperimental session, subjects were given experience with the stimuli and with the task of mental rotation. The subject was first shown a sample "same" stimulus and read the following instructions:

"As you can see, these are both the same shape. If you mentally turn the right stimulus clockwise you can imagine it in the same position as the left stimulus. When you see that the right picture can be turned into the left picture, signal *same* with your right-hand switch. [The stimulus was then advanced to a sample "different" trial.] This time the right-hand shape cannot be rotated in any direction to bring it into correspondence with the left picture: they are mirror images. When you see two figures which cannot be rotated into each other, signal *different* with your left-hand switch.

"Thus, your task is to turn the right figure clockwise to tell if it is a rotation or a mirror image. You must do this quickly, but with as few errors as possible. You will see many different shapes, some of which will look alike, so be careful. Remember, the most important thing is for you to rotate the right-hand shape clockwise, do not use any other strategy but mental rotation. If you do, please inform the experimenter." After the instructions were read, questions were answered, and the procedure further clarified, if necessary.

The next session was a familiarizing experimental session consisting of 300 trials in random orders. The subject then returned on 2 subsequent days for repetitions of the first sessions with new orders.

RESULTS

Mean reaction times for "same" judgments, as a function of angular difference in orientation for each shape, for each subject, are shown in Figure 2. ("Different" judgments are not used in these comparisons because they are not orderly, presumably reflecting a more variable mix of strategies and processes.) Slopes and intercepts of the linear regressions of "same" judgment

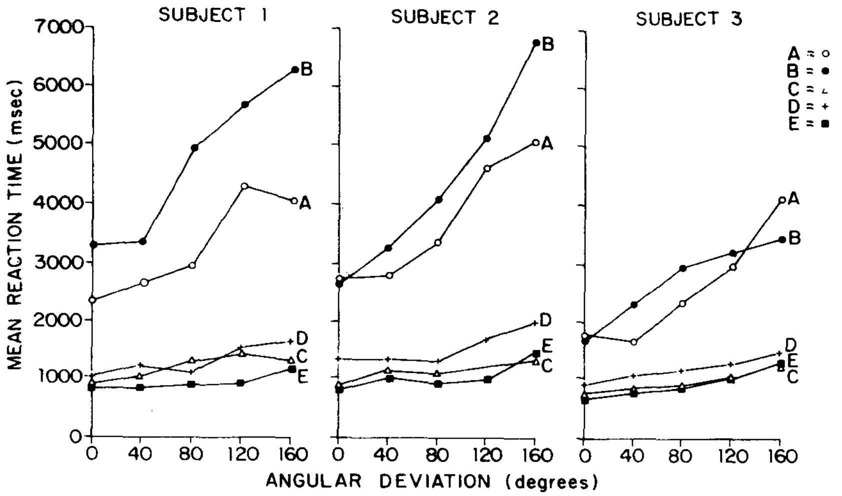

Figure 2. Mean reaction times for "same" judgments as a function of angular difference in orientation, for each shape and for each subject.

times on angular differences in orientation were found for each trial for each subject. Analyses of variance of the 12 trials (two sessions) per shape, for each subject, showed the effect of shape to be significant on slope [$F(4,55) = 12.85, 20.17, 21.29, p < .001$, for Subjects 1, 2, and 3, respectively] and on intercept [$F(4,55) = 28.20, 63.64, 124.15, p < .001$]. For all subjects, Shapes A and B were significantly higher ($p < .01$) in both slopes and intercepts than Shapes C and D; for Subjects 1 and 2, there were no differences in slope or intercept between Shapes A and B, Shapes C and D, or the average of C and D compared to E; for Subject 3, the intercept for B was higher than for A ($p < .01$), D was higher than C ($p < .05$), and the average intercept of C and D was higher than that of E ($p < .05$), by S test.

The means and standard deviations of slopes and intercepts for each shape are given for each subject in Table 1. The values of r shown there are for regression lines fitted to all of the "same" judgment times obtained with each subject at a given angular difference for each shape.

DISCUSSION

The shapes with salient landmarks (C, D, E) have lower slopes and intercepts in their time/angle function than the shapes in which these features have been made less distinguishable (A and B). This difference is not due simply to the greater complexity, per se, of the latter, inasmuch as Cooper (1975) found no such effects with the Attneave-Arnoult shapes. But it was the outcome to be expected if A and B required more comparisons to be made because of the relative inaccessibilities of their informative features and if the mental rotation task reflects the processes by which perceived forms are built up over successive glances (Hochberg, 1968).

Table 1
Regression Coefficients for Time as a Function of Angle

Subject	A M	A SD	B M	B SD	C M	C SD	D M	D SD	E M	E SD
					Slope					
1	12.9	6.3	19.9	10.5	4.0	3.2	3.4	2.5	2.7	2.0
2	15.8	14.0	22.0	11.3	2.3	2.2	3.3	4.4	3.9	4.7
3	14.8	6.3	11.0	5.5	2.6	1.3	2.6	2.4	3.5	1.9
					Intercept					
1	2234.0	549.4	2988.2	736.6	875.2	275.6	1042.7	158.9	666.2	92.8
2	2444.2	1135.3	2446.8	1134.5	927.9	133.4	1272.0	416.8	708.5	610.9
3	1372.5	538.5	1927.0	635.3	736.2	126.6	951.2	241.3	631.9	123.8
					r					
1	.61		.51		.27		.25		.28	
2	.59		.68		.29		.25		.19	
3	.58		.54		.54		.39		.56	
Mean Errors	3.7		4.0		1.7		4.3		0.7	

Note–The slopes and intercepts (in milliseconds) are means of the coefficients of lines fitted to each of the 12 trials of five angles per trial. The values of r are obtained from lines fitted to all of the 60 responses to each shape.

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