

Speed of size scaling in human vision*

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Ss compared the forms of pairs of rapidly presented rectangles. The rectangles varied in size and frontal plane orientation. The speed of mental size scaling was estimated from the relationship of judgment time to the size discrepancy between the rectangles. In addition, the speed of mental rotation was estimated by the increase in judgment time produced by a discrepancy between the orientations of the rectangles. Size scaling and mental rotation seem to be largely independent of one another.

Humans continue to recognize one another despite the changes in size of retinal image which accompany changes in viewing distance. This is evidence of size constancy. In general, any optical or biological pattern recognition system exhibits size constancy when it gives invariant responses to visual patterns which vary in their proximal dimensions (Hochberg, 1965). Size constancy in humans implies some kind of scaling or "normalizing" of the neural sequelae of retinal responses (Richards, 1968). We have measured the rate at which size scaling takes place by observing the time required to compare forms of varying size of retinal image. In addition, our results suggest that size scaling can go on undisturbed by other normalizing activities which the observer must perform.

On each trial, our Ss saw two briefly presented concentric rectangles in rapid succession. The height-to-width ratios or "forms"¹ of these rectangles varied as did their sizes. The S's task was to judge whether the forms of the two rectangles were the same or different. Whenever the rectangles were the same size, the task was simplified; when the two rectangles were of different sizes, the task proved more difficult. We used the relationship between judgment time and the targets' size difference to estimate the speed of size scaling. We were also interested in how the rate of such size scaling might be affected by other, concomitant normalizing operations required of our Os. Conditions were introduced which permitted the measurement of the speed of mental rotation of the rectangular stimuli (Shepard & Metzler, 1971), as well as the independence of mental rotation and size-scaling operations. These conditions will be described below.

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METHOD

The Ss sat 57 cm from a computer controlled cathode ray display coated with a rapidly decaying Type P-31 phosphor. The sequence of events on a trial was as follows: a standard rectangle was presented for 50 msec. This standard was selected randomly from three possible forms: 37 x 11 mm, 25 x 16 mm, or 31 x 13 mm. The standard rectangle was presented with its longer axis vertical on half the trials and with its longer axis horizontal on the other half. Five-hundred and seventy milliseconds after the standard terminated, a second comparison rectangle was presented, also for 50 msec. This second rectangle was selected in a quasirandom fashion under the following constraints: on half the trials, standard and comparison stimuli had different forms; on one-quarter of the trials, standard and comparison stimuli were of the same form but differed by a 90-deg rotation in the S's frontal plane; on the remaining one-quarter of the trials, stimuli had both the same form and orientation. Within each of the possible relationships between standard comparison forms (different, same but rotated, and same and not rotated), there were seven different size relationships, each appearing equally often over the course of a session. The size relationship can be expressed as a ratio of the linear dimensions of the comparison rectangle to those of a standard of similar form: 0.5, 0.67, 1.00, 1.16, 1.33, and 1.50.

The Ss were instructed to decide as rapidly as possible, while making few errors, whether the two rectangles had the same or different forms. They were instructed that if the two rectangles were the same except for a 90-deg rotation, they should still be judged "same." Responses were made via telegraph keys. The computer recorded the response, the number of milliseconds intervening between the termination of the second stimulus and the response (hereafter "response time"), and the stimulus parameters for the trial. Five Ss each served individually in five 90-min sessions.

During each session, 435 trials were run in three blocks, with rest periods intervening. Only response times from trials on which the correct response was made were used in subsequent data analysis.²

RESULTS AND DISCUSSION

The major results of the experiment are shown in Fig. 1. The leftmost panel, labeled "nonrotated," shows the mean response times averaged across Ss and rectangle forms for all trials in which the two rectangles were the same form and, in addition, had the same orientation. The values on the abscissa represent the size of the second rectangle, going from the smallest (1), through the point at which the first and second rectangles were the same size (4), to the largest second rectangle (7). The mean response times first decrease with increasing size of the second rectangle, reach a minimum when both rectangles are the same size, and then increase again. The middle panel of Fig. 1 shows the analogous data for trials on which the two rectangles had the same form but on which the second was rotated through 90 deg in the S's frontal plane. The abscissa is as in the leftmost panel. Again, the response times first decrease with increasing size at the second rectangle, reach a minimum when the two stimuli are the same size, and increase as the second stimulus gets larger still. Times in the middle panel average 70 msec more than the corresponding times in the left panel. This difference between the two curves reflects the duration of operations required to compensate for the effects of the 90-deg rotation of comparison rectangles (in the middle panel). The rightmost panel shows the times for those trials on which the two rectangles had different forms.³

An analysis of variance on response times from "same" form trials (data in the left and middle panels of Fig. 1) indicated significant effects of stimulus size ($F = 8.31$, $df = 6,24$, $p < .01$) and stimulus rotation ($F = 132.49$, $df = 1,4$, $p < .01$). The interaction between these two variables was not significant ($F = 1.42$, $df = 6,24$, $p > .20$). The lack of interaction means that, to a first approximation, the forms of the curves in the left and middle panels of Fig. 1 may be treated as similar. A trend analysis of the size effect indicated that only the quadratic term was statistically significant. Guided by these findings, a multiple regression was done on data averaged between left and middle panels. Two line segments were fit with their intersection forced through the point from conditions in which both stimuli

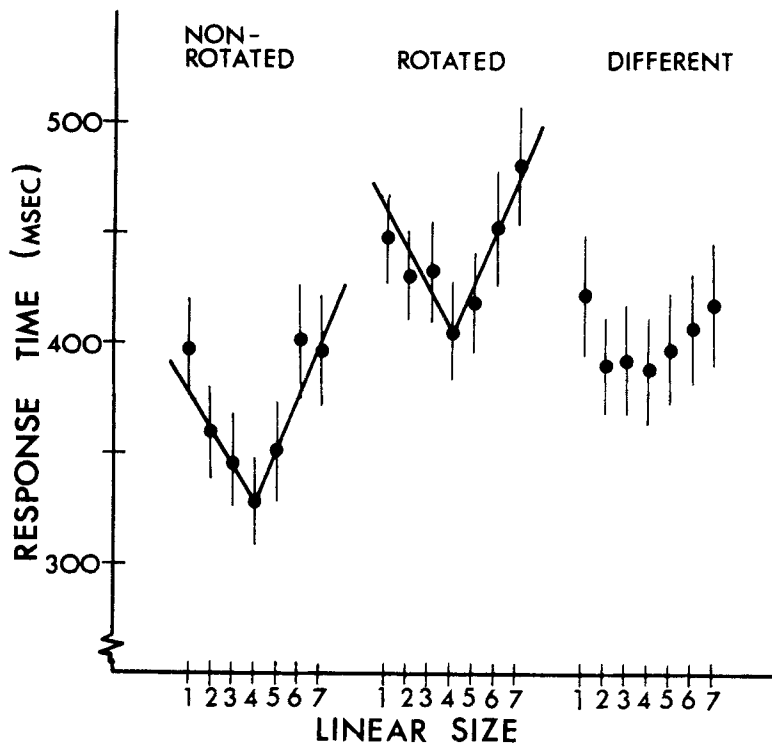


Fig. 1. Mean response time as a function of the size of the second of two stimulus rectangles. Shown are data for conditions in which the two rectangles had the same form and orientation ("nonrotated"), in which the two rectangles had the same form but differed by 90 deg in their frontal plane orientations ("rotated"), and in which the rectangles had different forms ("different"). In each instance, the abscissa value 4 corresponds to conditions in which the two rectangles were the same size; smaller numbers mean that the second was smaller than the first and larger numbers that it was larger (see text).

were the same size. The curves shown in Fig. 1 are the best-fitting regression lines. The slope of the decreasing function is -17.9 msec, and that of the increasing line segment is 25 msec. This difference in slope is small enough to make us extremely cautious about rejecting the null hypothesis of no difference between the two line segments. For our stimuli then, we may assume that the size-scaling processing, whatever its nature, requires approximately 70 msec to scale upwards in size (by 50%) or downwards in size (by 50%).

In a related experiment, Sekuler & Abrams (1968) showed that geometric patterns, though composed of identifiable segments, could, if simple enough, be processed as wholes. For the present experiment, we chose stimulus configurations that should have been simple enough to be processed in a similar fashion. The fact that rotation through 90 deg only increased response times by about 70 msec raises some questions about the relationship between the present experiment and one reported by Shepard & Metzler (1971). They had Ss judge the sameness of pairs of complex perspective line drawings of 10 chained cube-like components.

Differences in frontal plane orientation between two figures slowed down the S's response times. Response times increased linearly with increasing difference in the frontal plane orientations of the two figures, but did so at a rate far slower than the 70 msec/ 90 deg of rotation which we found. Apparently, the mental rotation of complex figures like those of Shepard and Metzler requires far more cognitive effort than does that of our own, simpler figures. This discrepancy implies that before our results for the time of mental size scaling can be generalized further, additional experiments should be carried out with figures of varying complexity.

The finding, in the present study, that size scaling in human vision operates at a measurable rate is not wholly unanticipated. Leibowitz, Toffey, & Searle (1966) have found, for example, that a related phenomenon, shape constancy, also requires an appreciable time to develop. Moreover, Marg & Adams (1970) have recently described the behavior of single cells in the human visual cortex that might provide a model for the size scaling we have examined. Several of the cells Marg

and Adams describe showed changes in the angular size of their receptive fields as the patient altered his fixation distance. Such cells might be likened to a zoom lens whose focal length, at any given moment, was coupled to a neural system which registered fixation distance. Since Ss in our experiment had to compare the iconic representations of the two stimuli on each trial, rather than two actually present external stimuli, we must be rather careful about assigning a putative neural locus to the mechanism whose behavior shows up in our experiment. However, without prematurely forcing an anatomical locus on our data, we may say—if only metaphorically—that the present experiment provides an estimate of the operating speed of the zoom lens of the mind's eye (Hochberg, 1968).

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NOTES

1. The usage of the term "form" follows that of Sutherland (1961). He writes that "Differences in form" refer to differences produced in the geometrical relationships of the contours of a figure other than differences produced by changes in orientation or by changes in size. 'Differences in shape' refer to changes produced in the geometrical relationships of the contours of a figure other than changes in size. Thus, a triangle and a circle differ both in form and shape, whereas a vertical and a horizontal rectangle of similar side ratios differ in shape, but not form [p. 32]."
2. Although the error trials were far fewer than the correct trials (about 10%), the basic pattern of results was similar for both.
3. The data in the rightmost panel, for "different" responses, cannot be analyzed in the same manner as those from the other panels, for the "same" responses. Data from "different" trials are heterogeneous in the sense that the difficulty of the judgment varied as a function of which of the 24 combinations of forms was used. In order for a proper analysis with homogeneous classes of stimuli, the data would have to be divided into those 24 classes as well as into the seven size categories, leaving far too few responses per condition to be meaningful.