The time it takes to make veridical size and distance judgments*

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Two experiments measuring the time it takes to make veridical size judgments under normal (unreduced) conditions of viewing showed that RT tended to increase with increases in viewing distance between 122 and 305 cm, even for targets subtending the same visual angle at all distances. Two experiments measuring the time it takes to judge distance under the same conditions did not reveal any difference in RT as a function of the extent-of-distance judged. Established accounts of size perception do not suggest an explanation of these findings.

The Ss in the first two experiments made judgments of the size of targets viewed under full-cue conditions, i.e., with unhindered access to distance information. Under these viewing conditions, it would be expected that size judgments would be independent of viewing distance. Indeed, it was our intention to insure that size constancy would prevail. The aim of our experiments was not to investigate once again the conditions that determine veridical size perception, but rather to examine the possibility that within a given class of size judgments, the set of veridical judgments, there are differences in processing time as a function of the variables that enter into the size judgments.

Nothing in the conventional analysis of size perception (Epstein, Park, & Casey, 1961; Hochberg, 1972) suggests differences in processing time. The size-distance invariance hypothesis which provides the framework for the conventional analysis does not address itself to processing time, although there is an unexpressed implication that the computation-like process is instantaneous. Nevertheless, there was reason to suspect that processing time would not be constant for all combinations of size, distance, and visual angle. In a series of experiments dealing with the judgment of shape of planar forms, Massaro (1973) found that RT of correct judgment for forms that were rotated in depth was an increasing function of the form's rotation from the frontoparallel plane. This was true both for same-difference judgments of pairs of shapes and for correct identifications of individually presented shapes. Since the processing of retinal size and distance cues is analogous to the processing of projective shape and slant

cues, similar RT functions might be present in size judgments as were found for shape judgments.

EXPERIMENT I

Method

Subjects

The Ss were nine volunteer undergraduates with normal or corrected vision.

Apparatus

The apparatus consisted of three units: a display unit, a four-digit electronic counter/timer (Psionix 1248B), and a response unit. The floor of the display unit was an unpainted sheet of wood, 360 cm long and 90 cm wide. An upright flat back wooden panel at the far end served as the backdrop for the display. Another upright panel at the near end was equipped with an extended padded viewer. Normal fluorescent room illumination prevailed. A fall-type shutter was used to occlude S's view of the stimuli. When the shutter was released, the viewing window was instantaneously cleared, allowing an unrestricted view of the floor and background as well as the targets. The response unit consisted of two spring-loaded pushbuttons which were mounted 15 cm apart below the viewing window. The timer was started by the fall of the shutter and stopped by the pushbutton response. RT was measured in milliseconds. Two lights on the timer panel indicated to E what response was made.

Stimuli

The stimuli were four pairs of white cardboard rectangles, 5.1-12.7 cm in height (2, 3, 4, and 5 in.) and 2.5 cm in width (1 in.). Each rectangle was mounted separately on a metal rod (.3 cm in diam) with its long dimension upright. The center of each rectangle was at constant height, aligned with S's line of sight. The supporting rod was inserted into a 5.1 x 5.1 cm metal base. The stimuli were presented 122, 183, 244, or 305 cm (4, 6, 8, or 10 ft) from S. Accordingly, the 2-in. rectangle at 4 ft, the 3-in. rectangle at 6 ft, the 4-in. rectangle at 8 ft, and the 5-in. rectangle at 10 ft subtended a constant visual angle of 2 deg 25 min. The lateral separation between the centers of the two stimuli at the viewing distance of 122 cm was 5.1 cm. For greater viewing distance, the lateral separation was increased proportionally to maintain a constant angle of separation.

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Table 1
Relationship of Size, Distance, and Visual Angle in the Three Conditions and the Actual Pairings Presented

Condition	Relationship of Two Targets			Pairings		Correct Response
	Size	Distance	O			
I	S	S	S*	2-4 vs 2-4 4-8 vs 4-8	3-6 vs 3-6 5-10 vs 5-10	Same (4)
II	D	D	S*	5-10 vs 4-8 5-10 vs 2-4 4-8 vs 2-4	5-10 vs 3-6 4-8 vs 3-6 3-6 vs 2-4	Diff (6)
III	D	S	D	5-10 vs 4-10 5-10 vs 2-10 4-8 vs 3-8 3-6 vs 5-6 3-6 vs 2-6 2-4 vs 4-4	5-10 vs 3-10 4-8 vs 5-8 4-8 vs 2-8 3-6 vs 4-6 2-4 vs 5-4 2-4 vs 3-4	Diff (12)
IV	S	D	D	5-10 vs 5-8 5-10 vs 5-4 4-8 vs 4-6 3-6 vs 3-10 3-6 vs 3-4 2-4 vs 2-8	5-10 vs 5-6 4-8 vs 4-10 4-8 vs 4-4 3-6 vs 3-8 2-4 vs 2-10 2-4 vs 2-6	Same (12)

**In these cases, visual angle was constant over the range of distances. The first number designates size (inches); the second distance (feet) of the targets in each pair.*

Procedure and Design

In Experiment I, two same-size or different-size rectangles were presented simultaneously at the same distance or at different distances from S. The instructions required S to report sameness or difference with respect to height by pressing the "same" button when the two stimuli were judged to be the same physical size and the "different" button when they were judged to differ in size. The stimuli were viewed binocularly and head movements were unrestricted.

The Ss were tested on successive days, at the same time, for five sessions, each lasting 1 h. The first day was devoted to practice involving sample trials from all four experimental conditions. Table 1 describes the four experimental conditions which were formed by manipulating the relationship between the two paired stimuli with respect to objective size, objective distance, and visual angle. Four pairings were possible in Condition I and six in Condition II. In order to equalize the number of trials in each condition, each pair was repeated three times in Condition I and twice in Condition II. To make possible a binary response, the stimulus pairs in Condition I were combined with those in Condition II in one experimental session. Similarly, Conditions I and III, Conditions II and IV, and Conditions III and IV were combined for the remaining three experimental sessions. Thus, the probability that the stimulus pair would be the same and different was .5 for each session.

In each experimental session, there were 24 stimulus pairs (12 from each condition). Each of these 24 stimulus pairs was repeated four times (twice in one lateral arrangement and twice in reversed position), making 96 trials in each experimental session. The order of presentation of these stimulus pairs in each experimental session (for each of the four sets) was randomized independently for each S. Also, the order in which the four sets were assigned to the nine Ss was randomized. A rest pause of 5 min was provided midway in each session.

At the beginning of each session, the instructions were read and S was reacquainted with the four rectangles and the viewing box. The instructions encouraged S to respond as rapidly as possible without making errors. An objective size-matching set (see Epstein, 1963) was induced; S was explicitly instructed to respond to objective size. He was also told that the width of all

targets was the same and that he should disregard width. Before releasing the shutter, a ready signal was given and S was required to place his forehead on the padded extension of the viewing window and position his index finger on the pushbuttons. The shutter was reset manually after each response and the stimulus pair replaced by the next pair in the random series. The stimuli were always removed and replaced whether a change was called for by the random sequence or not. After every response, information was given orally about the correctness of the response. If a response was wrong, the trial was repeated later during the same session. Since we wished to confine our analysis to correct responses, this procedure insured that the full complement of RTs would be considered under every condition. As it turned out, wrong responses were very infrequent. After the final session, Ss rated the order of difficulty of the four conditions.

Results

In Condition I, the two targets on a given trial were the same objective size and both were located at the same distance. The objective size of the pairs presented at the four distances varied in direct proportion to distance. Therefore, in Condition I, all of the targets subtended the same visual angle regardless of viewing distance. The mean same RTs are shown in Fig. 1 as a function of egocentric distance, i.e., absolute distance from S. Also shown is a line that was fitted by least squares and its equation. Same RT in Condition I was a linear increasing function of egocentric distance. Analysis of variance showed a significant effect on RT associated with egocentric distance [$F(3,24) = 9.1$, $p < .01$]. The linear component was significant [$F(1,24) = 29.75$, $p < .01$], accounting for 99.6% of the variance. The function in Fig. 1 could also be obtained by plotting RT against absolute size, since in Condition I size and distance changes were correlated perfectly. But it seems

implausible that RT could be meaningfully related to size, since absolute size was irrelevant to S's task. Furthermore, knowledge of absolute size normally would be the output of processing visual angle and distance, so it is more likely that distance was the important source of variance in RT.

In Condition IV, the two stimuli in each trial were the same size but were presented at different egocentric distances. Figures 2 and 3 plot same RT as a function of exocentric distance, i.e., separation between the two targets. In Fig. 2, RT is plotted for targets at each distance when paired with a target at every other distance. Thus, the uppermost curve shows the RTs when one of the targets (A) was at 10 ft and was paired on various trials with a target (B) at 4, 6, or 8 ft, representing exocentric separations of 6, 4, and 2 ft, respectively. In Fig. 3, the data are averaged over all size pairs at each exocentric distance. It is plain, both in Fig. 2 and in Fig. 3, that exocentric separation did not affect RT systematically. It is worth noting that since variations of exocentric separation produce changes in the magnitude of the difference between the visual angles subtended by the two standards, we may conclude also that visual angle comparisons did not figure prominently in Conditions IV or I.

Inasmuch as the results of Condition I strongly indicate that egocentric distance is important, we plotted the data of Condition IV as a function of egocentric distance. However, since the two targets on each trial were at different distances, the average of the two egocentric distances was selected as the egocentric distance for that trial. The data are plotted in Fig. 1, along with the data from Condition I for comparison. The slopes of the best-fitting lines are strikingly similar.

Fig. 1. Mean same RT in Condition I and Condition IV as a function of egocentric distance. In the case of Condition IV, distance is the average distance of the two targets.

Fig. 2. Mean same RT in Condition IV for all pairs of egocentric distances.

Fig. 3. Mean same RT in Condition IV for all sized targets combined as a function of the distance separating the two targets (exocentric distance).

Only the intercepts of the two curves differ. It took longer for S to judge the sizes of the two stimuli when the egocentric distances of the two were different. Analysis of variance of the data for Condition IV in Fig. 1 shows significant RT differences associated with average egocentric distance [$F(4,32) = 7.19, p < .01$]. The linear component in Fig. 4 is significant [$F(1,32) = 24.57, p < .01$], accounting for 85.5% of the variance. No other components were significant.

Figure 4 shows the mean different RTs for Condition III as a function of egocentric distance. RT increased with increases in egocentric distance. Analysis of variance showed significant RT differences associated with distance [$F(3,24) = 38.09, p < .02$]. The linear component accounted for 86.5% of the variance. The quadratic and cubic components were also significant. The results for the different RTs in Condition II are plotted against average egocentric distance in Fig. 5. These results are consistent with the results for Condition III. Different RT increased with average

Fig. 4. Mean different RT as a function of egocentric distance in Condition III.

egocentric distance [$F(4,32) = 20.24, p < .01$], and the linear component [$F(1,32) = 65.54, p < .01$] accounted for 80.9% of the variance. The cubic component was also significant, accounting for 18% of the variance.

The average rated difficulty of the four conditions was I, III, IV, II, in order of increasing difficulty. The mean RT for the four conditions was 543, 547, 580, and 600 msec for Conditions I, III, IV, and II, respectively. Thus, there was a perfect positive correlation between rated difficulty and mean RT. The Ss' difficulty ratings also correlated perfectly with the obtained error rates: I—1.38%, III—4.39%, IV—5.55%, II—6.48%. The average error rate over all conditions was 4.45%, 154 errors in a total of 3,456 judgments. Conditions II and IV, which were most difficult by all three criteria, were the conditions which presented the two targets at different egocentric distances.

EXPERIMENT II

Experiment II also was concerned with size judgment under full-cue conditions, but instead of a same-different task, a new procedure was used, adapted from the memory search task introduced by Sternberg (1966, 1969). The S viewed a single rectangle and judged whether it was the previously identified positive target or a member of the previously identified negative set. In the same-different task, S was not required to evaluate the absolute size of the target. Only a relative size judgment was required. In addition, no memory comparisons were necessary, since both targets involved in the comparison were present simultaneously. The single-target procedure of Experiment II is essentially a recognition task, which differs from the same-different task in respect to both of the considerations above. In the single-target task, we assume that S encodes the absolute size of the target and then compares it with the sizes in memory to determine whether its match is accompanied by a positive or a negative tag. Since there is no apparent reason for the comparison stage to

depend on viewing distance, we may safely surmise that it is the first stage, encoding absolute size, that is affected. Thus, the results of this procedure will allow us to generalize our conclusion to include perceived absolute size, as well as perceived relative size.

Method

Subjects

Fifteen undergraduates with no previous experience in size-judgment experiments served as Ss. All Ss had normal or corrected vision.

Stimuli and Apparatus

The stimuli and apparatus of Experiment I were used again.

Procedure

At the onset of each experimental session, S was shown the set of four rectangles and he was familiarized with their sizes. Then a single rectangle was selected and identified as the positive target for that session. The other rectangles were removed and S was encouraged to examine the positive target visually and haptically until S felt confident that he would have no difficulty in identifying it. A different positive target was selected on each of four successive daily experimental sessions. The first day was devoted to practice with all four sizes. The experimental task presented a single rectangle on each trial. The S was instructed to press one button if the stimulus was the positive target and the other if it was a member of the negative set.

Each experimental session consisted of 96 trials. To achieve equiprobability of positives and negatives, 48 trials presented the positive target and 48 trials were allocated equally among the three members of the negative set. Each of the four targets was presented an equal number of times at each of the four distances. Order of presentation was random.

Fig. 5. Mean different RT as a function of average egocentric distance in Condition II.

Results

Since the positive and negative RTs were not found to differ significantly, the two types of responses have been pooled for graphic representation in Fig. 6. The curve labeled "total responses" was obtained by combining the data for all four sizes at each distance. Therefore, for these data, the average physical size was constant at all of the distances and the average visual angle diminished with each increment of distance. The curve labeled "visual angle constant" was obtained by plotting the means of a subset of trials at each distance, 2-in. target at 4 ft, 3-in. at 6 ft, 4-in. at 8 ft, and 5-in. at 10 ft, so that this curve represents RT as a function of egocentric distance for targets that subtended the same visual angle. Although the functions in Fig. 7 are nonmonotonic, RT tended to increase as a function of egocentric distance. Analysis of the total response data showed that both linear and quadratic components were significant ($p < .01$); the linear component accounted for 58% of the variance and the quadratic component 42% of the variance. Although the main effect of distance was significant ($p < .01$), Duncan's multiple range test showed that RTs at 4, 6, and 8 ft did not differ, the main effect stemming from significantly longer RTs for the 10-ft distance. Analysis of the data for constant visual angle showed a significant effect on RT associated with distance [$F(3,42) = 9.22, p < .01$]. The linear and quadratic components were significant [linear, $F(1,42) = 20, p < .01$; quadratic, $F(1,42) = 7.48, p < .01$]. The linear component accounted for 72% of the variance and the quadratic component for 27% of the variance.

The overall error rate was 3.4% for positive targets and 3.9% for negative targets. The percent positive errors at each distance were 4.0, 3.0, 3.6, and 4.0 for distances 4, 6, 8, and 10 ft, respectively. For negative responses, the percent errors were 3.9, 4.2, 3.8, and 4.3 for the four distances.

Discussion

The results of Experiment I consistently showed that the time it takes to judge size veridically is not constant for all combinations of visual angle and distance. The results of Experiment II obviously were not as straightforward and systematic; however, the general trend was not inconsistent with the data of Experiment I.

The relationship between RT for size judgment and viewing distance cannot be attributed to differences in the registration of visual angle. This line of explanation might have been viable if our investigation had been confined to a target of constant physical size presented at various distances. In this case, as the viewing distance was increased, the visual angle would have decreased, leaving open the possibility that the registration of visual angle was responsible for the RT differences. However, both the same RTs in Experiment I (Fig. 1, Condition I)

Fig. 6. Mean combined (negative and positive) RT for single-target presentation for all sizes combined at each distance (total responses) and for targets that subtend the same visual angle at each distance (visual angle constant).

and the RTs in Experiment II (Fig. 6) increased with distance when visual angle was constant at all distances. For the same reason, the different RTs in Experiment I cannot be attributed to diminishing visual angle differences with increasing distance. In Condition II, the difference between the visual angles subtended by the two targets at the various distances was constant. For example, the pair 5-10 vs 4-8 (average egocentric distance = 9 ft) provides the same absolute and relative visual angle as the pair 3-6 vs 2-4 (average egocentric distance = 5 ft) and cannot be distinguished on the basis of visual angle, yet the different RT is much longer for the former pair.

Nor is it convincing to refer the RT differences on the same-difference task to differences in perceived size. The argument could be made that inasmuch as in Condition I of Experiment I the targets increased in size as distance increased, then, given size constancy, we may assume that perceived size also increased with viewing distance. On the further assumption that larger perceived size requires a greater difference in size to be equally noticeable, the RT differences can be attributed to differences in the jnd for size. There are two principal objections to this account of Experiment I: (1) Weber's law was not intended to apply to two targets that are presented side by side for simultaneous viewing, and Ono (1967) has shown in experiments on the discriminability of line length that Weber's law does not in fact apply under such conditions. (2) If the account is correct, then, when the same pair of targets, e.g., two 5-in. targets, is presented at different distances, there should be no RT differences associated with distance. The data in Condition IV can be regrouped to test this prediction. For example, one can look at the same RTs for the pair of 5-in. targets presented at average egocentric distances of 7, 8, and 9 ft or the pair of 3-in. targets presented at distances of 5, 7, and 8 ft. The result of this examination does not support the implication of

the size account: RT increases with increasing average egocentric distance when the same-sized pair is presented at each distance.

Although there is nothing in the conventional analysis of size perception that could lead us to predict this result, the outcome is compatible with the findings for shape judgments obtained by Massaro (1973). In that study, the variance in shape-judgment RT was related to degree of rotation from the frontoparallel plane. In the present study, the variance in size-judgment RT was related to the egocentric distance of the target. The principal prospect for integrating the present findings with the conventional account of size perception is in examination of the time it takes to judge egocentric distance. Since the hypothesis posits that perceived distance interacts with visual angle to determine perceived size, it would take longer to judge size under conditions that require a longer time to judge distance. If the time to judge distance increases as distance to be judged increases, then the RT function for size could be explained. The matter can be settled by securing RT data for distance judgments. But it must be admitted that there is no compelling reason for expecting RT for distance judgment to vary. Increasing RT as a function of distance might occur if S defers a final decision about distance until he has properly converged for the distance of the target. Convergence movements are quite slow (Alpern, 1972), and, assuming that in the foreperiod which precedes presentation of the target(s) S is converged for a near distance, e.g., arm's length, then convergence time may cause RT for distance to increase as distance increases. Another possibility is that S is less confident of his judgments for greater distances leading to longer RTs. This could be the result of inexperience in judging distances, particularly in judging distances beyond arm's length. Experiments III and IV were designed to examine the time it takes to make judgments of distance under the conditions that prevailed in Experiments I and II.

EXPERIMENT III

The experimental arrangement, targets presented to S, and procedure of Experiment III were carried over unchanged from Experiment I. The only difference was that in Experiment III, S was instructed to make same-different judgments of objective distance. The S was encouraged to base his same-different response on distance judgment and not to rely unduly on size cues, inasmuch as all sizes would be presented at all distances. However, because the implications of these distance judgments for an interpretation of the size judgments in Experiment I depend on the comparability of the two experimental situations, we did not wish S to ignore the rectangles entirely, relying on the supporting rod to act as a distance marker. Accordingly, S was informed that the rectangles occasionally would appear with back sides facing him and that on these infrequent occasions, he should refrain from button pushing.

Method

Subjects

Ten new undergraduates with no prior experience in the size-judgment experiments served as paid Ss. Five of the 10 Ss had previously been tested with the distance-judgment procedure to be reported in the description of Experiment IV.

Results

There was no evidence of systematic differences in RT as a function of the extent of the distance judged. Under Conditions I, II, and III, separate analysis of variance failed to show any RT differences even approaching significance. The slope of the RT function was essentially zero in each case. The mean RT was 376.5, 380.5, and 372.5 msec for Conditions I, II, and III, respectively. Unlike these three conditions, the mean different RTs under Condition IV did differ as a function of (average) egocentric distance [$F(4,36) = 7.02$, $p < .01$], but not in any way that could be systematically related to the size judgments under Condition IV in Experiment I. The mean RTs for the five average egocentric distances in Condition IV were 393, 373, 380, 373, and 404 msec for the distances of 5, 6, 7, 8, and 9 ft, respectively. Only the quadratic component was significant. The mean RT for Condition IV was 384 msec.

EXPERIMENT IV

Experiment IV was modeled after Experiment II in all respects, except that distance judgments were solicited instead of size judgments. At the outset of each experimental session, S was familiarized with the four distances first by having E mark off the distances in the absence of targets, then by showing S a randomly selected member of the set of rectangles at each of the distances. Familiarization was continued until S had learned all four distances. Then a positive distance was identified and testing commenced following the procedure and presentation plan of Experiment II. As in Experiment III, S was encouraged not to rely unduly on the size of the target. Also, as in Experiment III, precautions were taken to insure that S would not ignore the target.

Method

Subjects

The same 10 Ss who served in Experiment III were paid to serve in Experiment IV. However, for only 5 of the Ss did the procedure of Experiment III actually precede testing with the procedure of Experiment IV.

Results

The results showed no RT differences associated with extent of distance judged either for positive or for

negative judgments ($F < 1$). The only significant difference was a faster RT for positive responses (335 msec) compared to negative responses (353 msec) [$F(1,9) = 14.37, p < .01$].

DISCUSSION

Experiments I and II showed that size judgments take longer the more distant the target is from the O. In any situation that allows visual angle and distance to vary independently, it will be necessary to take distance into account in judging size. Accordingly, it was plausible that the RT function for size might be due to the time it takes to judge distance. But the results of Experiments III and IV gave no support to this interpretation. There was no evidence that the RT for judgments of distance increases with increasing distance over the range of distances for which RT for size judgments were found to increase.

Although RT for size judgment and RT for distance judgment did not covary, a consistent relationship between the times required for the two types of judgment was clearly present. Table 2 shows the mean RT for size and distance judgment. For all four conditions in Experiments I and III and both for positive and negative responses in Experiments II and IV, distance judgments were significantly faster than size judgments. The mean difference was 189 msec for the two-target presentations and 186 msec for the single-target presentations. Since the determination of relative objective size and absolute size depends in the case of unfamiliar objects on the prior determination of distance, it is understandable that distance judgments should be faster.

There is no immediately obvious explanation of our findings. It is possible that our conclusion that the RT data cannot be attributed to the time required for the hypothetically prior registration of distance is premature. This conclusion might be questioned on the grounds that the time to register distance in the service of veridical size perception cannot be inferred from the time it takes to judge distance in a distance-judgment task. There is no obvious way to test this account. In any event, it would leave us the problem of explaining the two RT functions for distance. Finally, it may be proposed that the RT differences are differences in the time required to carry out the combinatorial stage of size perception. According to the processing model represented in the invariance hypothesis, size perception

Table 2
Mean RT (Milliseconds) for Size Judgment Compared to Mean RT for Distance Judgment

Condition	Correct Response	Size Judgment RT	Distance Judgment RT
		Experiment I	Experiment III
I	Same	543	376
II	Diff	600	380
III	Diff	547	372
IV	Same	580	384
		Experiment II	Experiment IV
	Positive	540	335
	Negative	520	353

consists of three stages, the first two, registration of image size and registration of distance, carried out in parallel processing, followed by a combinatorial stage, in which registered size and distance are combined (multiplicatively) to yield the output, judged size. Although there is nothing in the usual formulation to suggest that the duration of the combinatorial stage should depend on the values for the two variables that enter into the combination, this remains a possibility.

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