A Variety of Size and Distance Judgments under Monocular Observation: Instructions and Individual Differences

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The study to be reported here is concerned with the relation between size estimates and distance estimates. Let us consider the situation where two targets of similar shape but different retinal sizes are successively presented under a reduced-cue condition. In that situation, the target of smaller retinal size is usually judged smaller and farther away than target of larger retinal size. From this well-established finding, a number of researchers have assumed that both size estimates and distance estimates are directly determined by relative retinal size (Epstein & Landauer, 1969; Oyama, 1974, 1977). Accordingly, this conventional account has been referred to as the *relative-retinal-size hypothesis*.

Higashiyama (1977, 1979) doubted the validity of this relative-retinal-size hypothesis and proposed a hierarchical model that is applied to reduced-cue as well as full-cue conditions. The hierarchical model consists of two processes involved in making judgments of size and distance—the primary process and the secondary process. The first assumption of the model is that the perceptual system initiates to operate with the primary processing. The primary process is a process of transforming the retinal image size of a target into primary perceived size. This is achieved by taking into account primary registered or perceived distance that is produced by primary distance cues. Primary distance cues contain any of classical distance cues that are available in constructing primary perceived size. Therefore, oculomotor cues, binocular retinal disparity, and motion parallax typically contribute to the achievement of primary distance perception.

The second assumption of the model is that a ratio of two primary perceived sizes determines a ratio of secondary perceived distances, which are different from primary perceived distances produced by primary distance cues. The target of smaller primary perceived size is judged to be farther away than the target of larger primary perceived size. In equational form, the relation between primary perceived size ($_{I}S'$) and secondary perceived distance ($_{II}D'$) are expressed as

$$_{I}S'_{C}/_{I}S'_{S} = {}_{II}D'_{S}/_{II}D'_{C}$$

or

$$_{I}S'_{C} \cdot {}_{II}D'_{C} = {}_{I}S'_{S} \cdot {}_{II}D'_{S} \qquad (1)$$

where subscripts C and S represent the comparison target and the standard target, respectively. Equation 1 has been called the *relative-perceived-size hypothesis*, since size perception is assumed to precede distance perception (Higashiyama, 1979).

Higashiyama (1979) found Equation 1 appropriate for describing the relation between apparent size and apparent distance under a reduced-cue condition. However, for the purpose of applying the hierarchical model to other conditions and making statistical treatments of the data possible, it may be helpful to generalize Equation 1 as

$$_{I}S'^{m}_{C} \cdot {}_{II}D'^{n}_{C} = k \qquad (2)$$

where m and n are constants and k is equal to the product of $_{I}S'_{S}$ and $_{II}D'_{S}$. Equation 2 will be called the *generalized-relative-perceived-size hypothesis*. Equation 2 can be written as

$$\log {}_{II}D'_{C} = -(m/n)\log {}_{I}S'_{C} + (\log k)/n. \qquad (3)$$

Thus, Equation 3 implies that the relation between log $_{I}S'_{C}$ and log $_{II}D'_{C}$ will be linear, with slope corresponding to $-(m/n)$ and intercept to $(\log k)/n$. Once the values of slope (A) and intercept (B) are experimentally known, m and n will be estimated by the equations:

$$m = -(A \log k)/B \tag{4}$$

and

$$n = (\log k)/B. \tag{5}$$

In a special case of $m = n = 1$, Equation 2 or 3 is equivalent to Equation 1.

The occurrence of secondary perceived distances sometimes entailis the secondary size perception that the two targets are the same target or identical sized targets (Gogel, 1964, 1969; Ittelson, 1960). From the point of view of mechanism producing size estimates, secondary perceived size is entirely different from primary perceived size. The primary perceived size is an automatic product resulting from the combination of retinal image size and primary distance cues, while the secondary perceived size is a somewhat higher-order product based on the assumption that the observer can make about the objective external world. The combination process of the secondary perceived size and distance is referred to as the secondary process.

The purpose of the present study was twofold. First, it was to examine how the instructions given to the observers influence on the relative activity of the modes of processing. The observers were required to make ratio judgments of size and distance under the apparent (Experiment 1) and objective (Experiment 2) instructions. An attempt was then made to compare the effects of those instructions on the relation between size estimates and distance estimates. Although in the previous studies (Higashiyama, 1977, 1979), the data were analyzed on the basis of the averages of the observers employed, the validity of the model should be tested using individual as well as grouped data. The second purpose of the study was to examine the causal chains among visual angle, size estimates, and distance estimates. Oyama (1977) applied partial correlation technique to various perceptual fields including brightness, shape, and size-and-distance perception, and under binocular observation, Oyama (1974) found visual angle and convergence angle to be direct determiners of both size and distance estimates. Thus, it may be interesting to determine causal relation under monocular observation.

Experiment 1

Method

Observers. The eight observers were undergraduates who were enrolled in the course of human sciences at the University of Osaka Prefecture. They had little experience in judgments of size and distance.

Apparatus. A mirror arrangement was used to provide the images of two targets in temporal succession on the common optical pathway. The apparatus was essentially the same as that used in the previous studies and the schematic drawings of it were presented elsewhere (Higashiyama, 1977, 1979).

Stimulus targets were different-sized squares, made by cutting openings in pieces of cardboad and covering them with translucent white paper. When the cardboad were illuminated from behind with a 20-watt bulb, the white squares appeared to be suspended in otherwise total darkness. All targets were presented at a constant viewing distance of 168.5 cm from the observer's eye position. Standard target subtenced a visual angel of 1.22 deg on a side; comparison targets subtended 7 different visual angles ranging from .408 deg to 2.040

deg in .272 deg steps.

Procedure. The observer was seated on a chair in a dim room. The observer's head was positioned in a chin rest so as to view the targets with his/her right eye through an aperture .5 cm in diameter that was immediate in front of the eye.

Each trial commenced with a brief signal of a chime. After a 2-sec blank interval, the standard was presented for 10 sec and, following a 1-sec interval, the comparison was illuminated for 10 sec. Intertrial interval was 10 sec during which the comparison was exchanged for the next trial.

Judgments of size and distance were obtained by the method of magnitude estimation. The experimenter instructed that the standard was assigned the number "10" in apparent size and the number "100" in apparent distance. The observer was then required to estimate apparent size and apparent distance of the comparison relative to the standard during the presentation of the comparison.

The observer received "apparent" instructions. The essential parts of the instruction are: "I am going to present you with a series of squares in total darkness. Two squares will be presented in quick temporal succession. Your task is to tell me how they appear in size and distance by assigning numbers to them. The first square we will call "10" in size and "100" in distance, respectively. your task will be to estimate the apparent size and the apparent distance of the second square. Please try to assign numbers proportional to your subjective impression. I want you to base your judgments on the way that the squares appear. Please disregard any information you may have about the physical or real size and distance of the squares." These instructions were entirely identical to those employed by Higashiyama (1979).

Each observer completed 10 blocks of 7 trials in a single session.

Each block of trials included 1 trial from each of the 7 comparison targets. Thus, any observer provided 10 size estimates and 10 distance estimates for any target.

For any trial, half of observers made the size judgment before making the distance judgment, and for the remaining observers the order was reversed.

Results

Figure 1 shows the results. Geometric means of size and distance estimates for each targets are individually plotted against visual angle of the comparison. All observers shows that as the visual angle of the comparison increases, size estimates of the comparison increase with decreasing distance estimates.

In order to evaluate the relation between size estimates and distance estimates, Equation 3 was applied to the individual as well as grouped data by means of least squares in log-log coordinates. The left portion of Table 1 shows parametric characteristics of the best fitting functions: slope $(-m/n)$, intercept $(\log k)/n$, and coefficient of determination (r^2). It is clear that all individual data are described by Equation 3. A t test revealed that no difference was evident between the mean slopes yielded by the two orders of judgments of size and distance $[t(6)=1.402,\ p>.05]$.

Since log k is equal to 3 in this experiment and the slopes and intercepts of Equation 3 are now known, the explicit values of m and n can be derived from Equations 4 and 5. The right two columns of Table 1 correspond to the m- and n-values thus estimated.

Figure 2 shows the best fitting function based on the grouped data. The horizontal and vertical lines attached to each data point show the standard deviations of size and distance estimates. The horizontal dotted line in that graph represents a prediction that the standard and

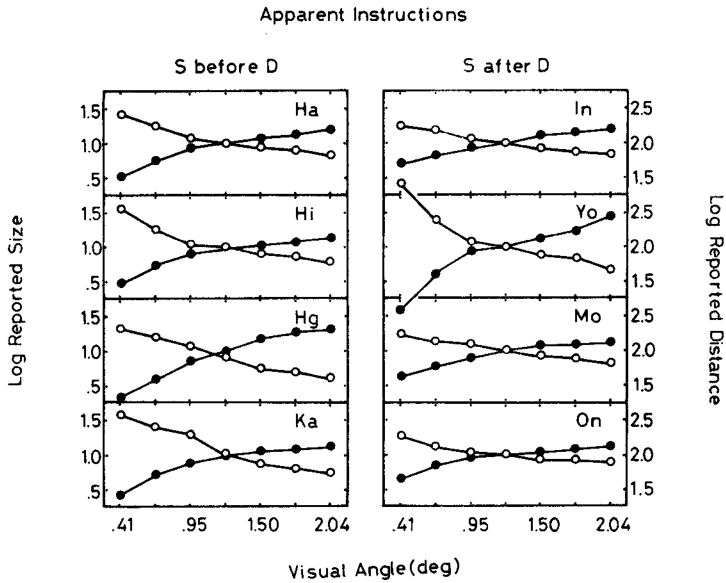

Figure 1. Log size estimates (●) and log distance estimates (○) as a function of visuals angle of the comparison under the apparent instructions. Each panel shows a different observer. The left 4 panels indicate the cases that size judgment was made before distance judgment; the right 4 panels indicate the cases that the order of judgments was reversed.

Table 1. Parameters of Equation 3 fitted to the relation between log S' and log D' under the apparent instructions.

Observer	Slope	Intercept	r^2	m	n
Ha	− .899	2.903	.996	.929	1.033
Hi	−1.168	3.111	.988	1.126	.964
Hg	− .738	2.617	.968	.846	1.146
Ka	−1.235	3.208	.914	1.155	.935
In	− .837	2.829	.988	.888	1.060
Yo	− .912	2.949	.994	.928	1.017
Mo	− .829	2.791	.960	.891	1.075
On	− .797	2.784	.988	.859	1.078
Combined	− .927	2.903	.996	.958	1.033

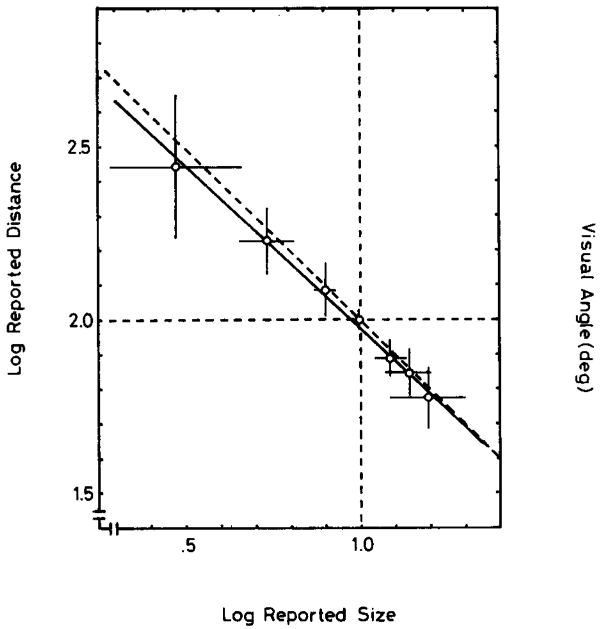

Figure 2. Log distance estimates as a function of log size estimates under the apparent instructions. N = 8.

the comparison are perceived equidistant with different perceived sizes. The vertical dotted line represents a prediction that the standard and the comparison are perceived as equisized targets located at different distances. The diagonal dotted line with a slope of negative unity is a prediction that m- and n-values in Equation 3 are srtictly equal to unity. Since an overall mean of individual slopes is not significantly different from negative unity [$t(7)=1.159$, $p>.051$], the grouped data may be approximately described by Equation 1.

In order to reveal the causal relation among visual angle (θ), size estimates (S'), and distance estimates (D'), simple correlations and first-order partial correlations were individually computed among log θ, log S', and log D'. The most left column of Table 2 shows the means and standard deviations of correlations averaged over the eight observers. From those results, it can be concluded that visual angle influences directly on size estimates but it does on distance estimates only through changes of size estimates. This finding is in agreement with the relative-perceived-size hypothesis but is contrary to the relative-visual-angle hypothesis, since if visual angle determined directly both size estimates and distance estimates, r(θ, S'/D') and r(θ, D'/S') would be significant and r(S', D'/θ) would not be significant.

Table 2. The results of partial correlation analyses applied to the size and distance judgments under the apparent and objective instructions.

	Apparent		Objective			
			Distance-invariance		Size-invariance	
Correlation	Mean	SD	Mean	SD	Mean	SD
r(θ, S')	.992***	.004	.969***	.031	.530	.533
r(θ, D')	−.987***	.005	−.975***	.025	.985***	.014
r(S', D')	−.987***	.013	.966***	.051	−.530*	.522
r(θ, S'/D')	.683***	.243	.431*	.604	.099	.621
r(θ, D'/S')	−.177	.399	−.602***	.398	−.915***	.142
r(S', D'/θ)	−.487*	.437	−.206	.672	−.075	.582

*: $p < .05$; **: $p < .01$; ***: $p < .001$

Experiment 2

The purpose of Experiment 2 was to examine the relation of size and distance estimates under the objective instructions.

Method

The experimental arrangement, targets presented to the observer, and procedure of Experiment 2 were carried over unchanged from Experiment 1. The only difference was that the observer was instructed to make ratio judgments of objective size and distance in Experiment 2. The essential parts of the "objective" instructions are: "I am going to present you with a series of squares in total darkness. Two squares will be presented in quick temporal succession. Your task is to tell me how they are in size and distance by assigning numbers of them. The first square we will call "10" in size and "100" in distance, respectively. Your task will be to guess the objective or real size and distance of the second square. Please try to assign numbers proportional to your objectively-estimated impression. By objective size I imply relative real area you would obtain if you were to fetch both targets and to compare them at your hands; by objective distance I mean relative real distance you would find if you were to take a ruler and to measure the distances from your eye position to both targets. I am not concerned with apparent size and apparent distance of the targets. I want you to make objectively precise judgments of size and distance."

The observers were 16 undergraduates who were enrolled in the course of human sciences at the University of Osaka Prefecture. They had little experience in judgments of size and distance.

Results

The individual data were analyzed in the same way as those obtained in Experiment 1. Figure 3 individually shows geometric means of size and distance estimates for each target plotted against visual angle of the comparison. In order to examine the validity of Equation 2, Equation 3 was applied to the individual data by means of least squares in

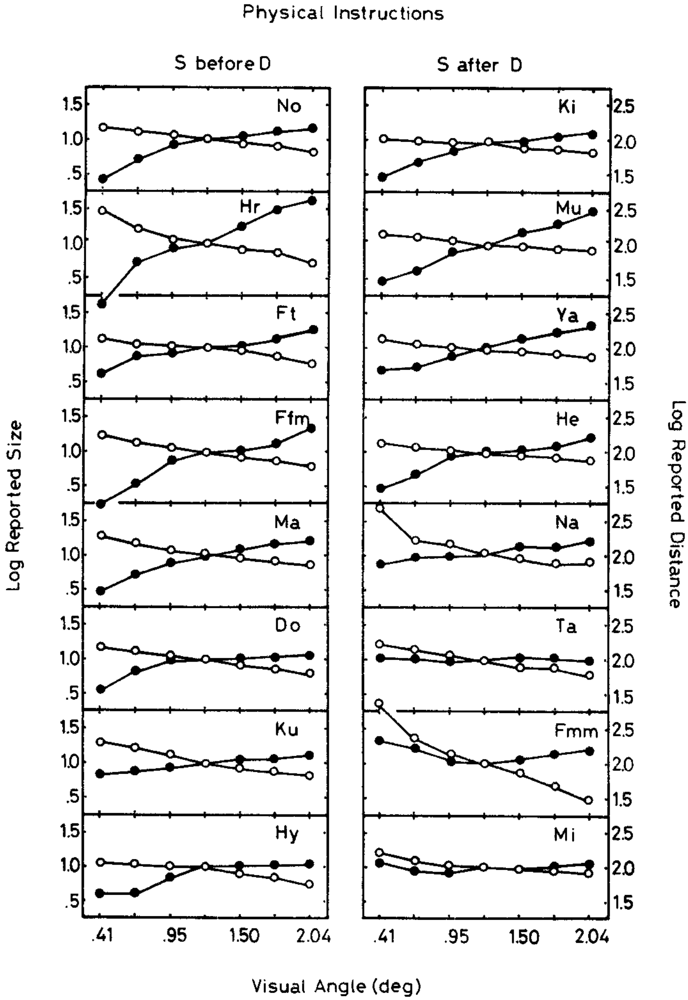

Figure 3. Log size estimates (●) and log distance estimates (○) as a function of visual angle of the comparison under the objective instructions. Each panel shows a different observer. The left 8 panels indicate the cases that size judgment was made before distance judgment; the right panels indicate the cases that the order of judgments was reversed.

log-log coordinates. Table 3 shows parametric characteristics of the best fitting functions: slope, intercept, coefficient of determination, and values of m and n.

Table 3. Parameters of Equation 3 fitted to the relation between log S' and log D' under the objective instructions

Observer	Slope	Intercept	r^2	m	n
No	− .442	2.418	.889	.548	1.241
Hr	− .479	2.521	.976	.570	1.190
Ft	− .542	2.497	.896	.651	1.201
Ffm	− .410	2.357	.949	.522	1.273
Ma	− .539	2.538	.995	.637	1.182
Do	− .621	2.560	.721	.728	1.172
Ku	−1.664	3.667	.988	1.361	.818
Hy	− .406	2.302	.548	.529	1.303
Ki	− .278	2.173	.702	.384	1.389
Mu	− .478	2.461	.996	.583	1.219
Ya	− .344	2.357	.984	.438	1.273
He	− .300	2.266	.967	.397	1.324
Na	−2.080	4.312	.764	1.447	.696
Ta	−1.037	3.063	.024	1.016	.979
Fmm	1.852	− .077	.209	72.156	−38.961
Mi	− .355	2.394	.050	.439	1.253

Together with Figure 3, Table 3 shows that there are three types of responses in terms of r^2. The first type is a group of the observers showing relatively higher values of r^2 ($r^2 \geq .85$). Figure 4 shows the relation between size estimates and distance estimates in log-log coordinates by combining the individual data of this group (N = 9). The relation was nearly linear ($r^2 = .990$) with a slope of −.501 and an intercept of 2.488. Thus, the parameters were m = .604 and n = 1.206.

The left graph of Figure 5 shows the second type of responses that were obtained from the four observers indicating intermediate values of r^2 ($.30 < r^2 < .85$). It is clear from the graph that the intermediate values of r^2 are attributed to the sharp turns of the data points at the standard position. Therefore, Equation 3 was applied separately to the lower and upper parts of the data points than the standard position. The results are given in Table 4 and are depicted in Fig. 5 as two limbs for each observer. As compared with the values of r^2 in Table 3, the corresponding values of r^2 given in Table 4 are improved for the three observers, Do. Hy, and Ki. This implies that Equation 3 is applicable to the data of those observers, but m and n change depending on whether the comparison was larger or smaller than the standard.

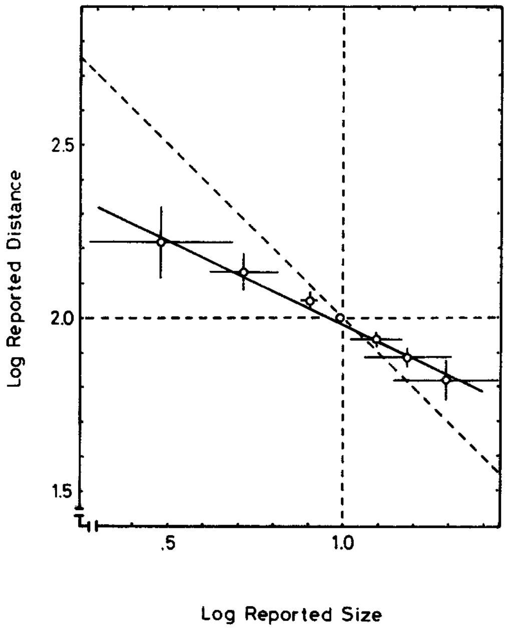

Figure 4. Log distance estimates as a function of log size estimates under the objective instructions. The data points were based on the individual data of 9 observers who showed higher values of r^2 between log S' and log D'.

The last type of responses were obtained from the three observers

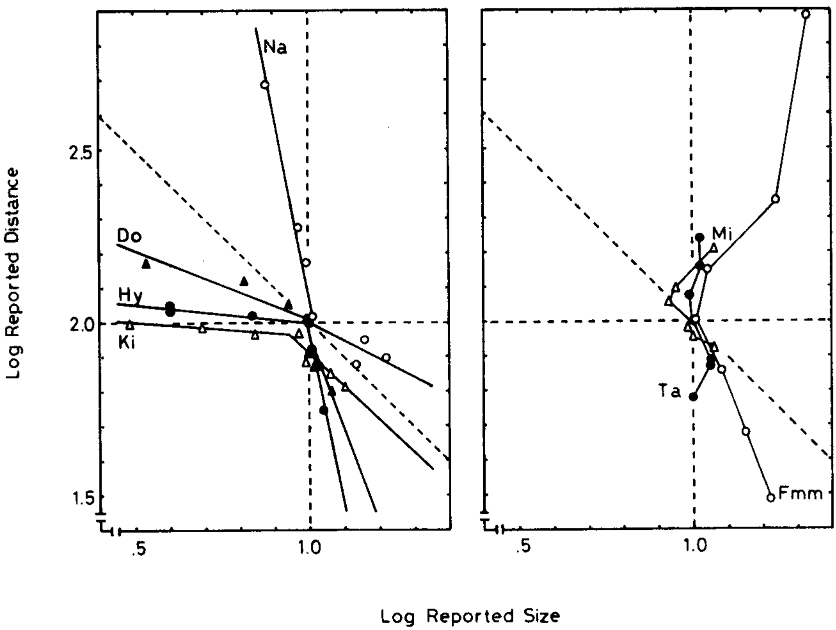

Figure 5. Log distance estimates as a function of log size estimates under the objective instructions. The left panel indicates the individual data of 4 observers who showed intermediate values of r^2 between log S' and log D'; the right panel those of 3 observers who showed nearly zero value of r^2 between log S' and log D'.

Table 4. Parameters of Equation 3 fitted separately to the lower and upper parts of the data points than the standard for the 4 observers showing intermediate values of r^2.

	Comparison					
	Smaller than the standard			Larger than the standard		
Observer	Slope	Intercept	r^2	Slope	Intercept	r^2
Do	−.361	2.384	.927	−2.757	4.724	.881
Hy	−.103	2.103	.928	5.392	7.387	.871
Ki	−.080	2.044	.949	−.973	2.886	.850
Na	−5.175	7.267	.984	.553	2.560	.637

showing nearly zero value of r^2 (Ta, Fmm, and Mi). The results are individually shown in the right graph of Fig. 5. The common characteristics of responses for those observers was that the data points scattered vertically or that the curves connecting the data point formed a long and slender C shape. This means that as the visual angle of the comparison increases, the distance estimates decrease with the size estimates invariant.

The partial correlation technique was applied to the individual data except for the second group of observers who showed intermediate correlations. The results are shown in the middle and right column of Table 2 by averaging over the first group of observers (distance-invariance group) and over the third group of observers (size-invariance group), respectively. We can find from Table 2 that in the distance-invariance group, visual angle influences directly on both size and distance estimates, whereas in the size-invariance group, distance estimates are determined directly by visual angle but size estimates are influenced by neither visual angle nor distance estimates.

Discussion

According to the hierarchical model proposed here, the primary and secondary perceptions are potentially produced whenever two targets are presented. Therefore, the perceptual system always experiences a perceptual conflict and makes a decision what type of perception should be reported. In this sense, instructions given to the observers are one of the most crucial variables contributing to the final decision of overt responses.

The present results showed that under the apparent instructions, the individual data were reasonably described by Equation 2 and the grouped data were fitted by Equation 1. Moreover, it is clear that visual angle influences on distance estimates only through size estimates. Those results are in agreement with the relative-perceived-size hypothesis and the apparent instructions are found to yield pure relation between primary perceived size and secondary perceived distance.

The objective instructions produced marked individual differences. These differences suggest three populations of observers identified as distance-invariance, size-invariance, and mixed-type judgments. For the distance-invariance judgments, the relation between size and distance estimates is described by Equation 2, but the distance estimates do not so greatly change with visual angle as size estimates. As is shown in Fig. 4, an increase of one unit in log size estimates is accompanied by a decrease of about a half unit in log distance estimates. Thus, as compared with the observers given the apparent instructions, the observers of distance-invariance judgments seem to have used primary distance cues actively. However, the results obtained from partial correlation technique can not be explained in terms of the hierarchical model, since the model predicts no possibility that visual angle influences directly on both size and distance estimates.

The observers of size-invariance judgments showed that distance estimates inversely varies with visual angle, while size estimates are approximately constant (Fig. 5). Furthermore, the results of partial correlation technique showed that distance estimates are directly influenced by visual angle, but size estimates are determined by an unknown factor that was not manipulated operationally in this study. Those findings are interpreted as an influence of the secondary processing on size and distance estimates.

In any event, it is clear that under the objective instructions, visual angle determines directly distance estimates. This results supports the relative-retinal-size hypothesis and rejects the relative-perceived-size hypothesis.

Besides the instructions given to the observers, there are two possible stimulus variables contributing to the final decision of overt responses. One is primary distance cues available in the visual field. Higashiyama (1977) determined relative effectiveness of the modes of processing under the full-cue, intermediate-cue, and reduced-cue conditions of observation. The results showed that the primary processing was exerted more dominantly in the full-cue condition, whereas the secondary processing was exerted more strongly in the reduced-cue condition. Gogel and Sturm (1972) also found similar results in a different theoretical contex.

Another variable is presentation order of targets. This variable was investigated vigorously by Gogel (1969) and Gogel and Sturm (1971). They presented two or three targets of different retinal sizes in various sequences under reduced-cue conditions and found that the first presented targets were perceived at a constant distance with different perceived sizes (primary perception), but the second or third presented targets were likely to be perceived as the same sized objects at different perceived distances (secondary perception).

Finally, some comments are useful to understand the hieranchical model in relation to the previous theories of space perception. The primary process involved in the model is equivalent to the taking-into-account theory of size perception (Epstein, 1973, 1977), but it is not identical with the size-distance-invariance hypothesis that is a modern mathematical version of the taking-into-account theory of size perception. For the purpose of comparing the primary process with the size-distance-invariance hypothesis, suppose two targets are presented at different distaces with a constant visual angle. According to the size-distance-invariance hypothesis, apparent size will be predicted to vary in proportion to apparent distance. On the other hand, the primary process will predict that primary perceived size increases with increasing primary perceived distance, but it does not necessarily assume the proportional covariation between primary perceived size and primary perceived distance. In this sense, the primary process is another version of the taking-into-account theory of size perception and is less restrictive than the size-distance-invariance hypothesis.

What We call here the secondary processing may be equivalent to the response-biasing mechanism termed the perspective attitude by Carlson (1960, 1962, 1977) and Carlson and Tassone (1962, 1971). Carlson and Tassone pointed out that normal adults believe that an object looks smaller at a greater distance. In other words, this belief implies that if we assumed two targets equal in objective size, the closer-appearing object is likely to be judged larger than the farther-appearing object. Although a number of studies (Carlson, 1960, 1962; Carlson and Tassone, 1967, 1971; Epstein, 1963) examined the effects of the perspective attitude to explain overconstancy that is often found under natural viewing situations, there is no reason the effect of the perspective attitude is limited to the natual viewing situations. In fact, the observer's assumption of objectively equisized targets under the perspective attitude seems to correspond to secondary perceived size of the hierarchical model, and the coupling judgments between smaller size and farther distance or between larger size and closer distance seem to be compatible with the implications of Equations 1 and 2.

Summary

The relation between size estimates (S') and distance estimates (D') of targets that were successively presented at a constant viewing dis-

tance under a reduced-cue condition was studied. In the first experiment performed for 8 observers with the apparent instructions, the grouped judgments were well described by the generalized-relative-perceived-size hypothesis ($S'^{m} \cdot D'^{n} = k$) with m = .95 and n = 1.0. In the second experiment performed for 16 observers with the objective instructions, the individual judgments were divided into three subgroups of observers. The grouped judgments of the 9 observers were described by the generalized-relative-perceived-size hypothesis with m = .6 and n = 1.2; other 3 observers showed that D' varied with visual angles of targets, whereas S' was likely to be constant for any target. The remaining 4 observers showed mixed patterns of the two typical responses. Furthermore, the results of partial correlation technique showed that under the apparent instructions, visual angle influences on distance estimates only through size estimates, while under the objective instructions, visual angle determines distance estimates without being mediated by size estimates.

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