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THE RELATIONAL DETERMINATION OF PERCEIVED SIZE[1]

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One generalization that is now rather widely accepted in the field of perception is that perceptual qualities are often determined by relational rather than by absolute characteristics of the stimulus. Of the many examples that could be given to illustrate the point we will restrict ourselves to two which have certain formal similarities to the problem we wish to discuss in this paper.

The first example is concerned with the problem of neutral or achromatic color. One might ask, what is the stimulus for the experience of a given shade of gray? In the achromatic series it would seem there is no simple stimulus for neutral color corresponding to the role that wave length plays in accounting for chromatic color. Intensity of stimulation is inadequate because this changes with every change in illumination whereas the particular gray perceived remains constant. It is true that the albedo or reflectance property of an object is fixed (i.e. a white surface is one that reflects roughly 80% of the light it receives, a black, one that reflects roughly 5%), but this is a statement about the external object. The problem remains of uncovering the invariant characteristic of the stimulus that makes possible the invariant perceptual experience. Wallach's (1948) solution of this problem was that the stimulus for a particular gray is the ratio of light intensities of neighboring retinal areas. He demonstrated that a given ratio of intensities (in an otherwise completely dark room) would always yield a given shade of gray. For example (Fig. 1) a disk of Intensity 5 (arbitrary units) surrounded by a ring of Intensity 10 would appear light gray; so would a disk of Intensity 25 surrounded by a ring of Intensity 50.

The second example is concerned with the problem of perceived speed. One might speculate that the determinant of the experienced velocity of an object is the rate at which its image traverses the retina. J. F. Brown (1931) has shown, however, that velocity depends not so much on absolute rate of displacement of an image on the retina as on the rate of displacement relative to a frame of reference. He presented his observers with two equidistant fields of dots (Fig. 2) moving behind apertures in an otherwise darkened room, the linear dimensions of one field being transposed by a given multiple of the other. He found that the dots in one field would appear to be moving at approximately the same speed as those in the other, not when they moved at

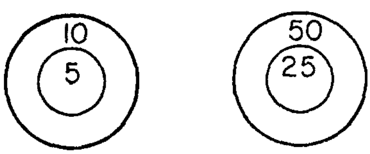

FIGURE 1.

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FIGURE 2.

the same absolute speed, but when they traversed their respective apertures at the same relative rate. Thus, for example, when the dimensions of fields were transposed in the ratio of 2:1, equal phenomenal speed resulted only when the objective speed was also transposed by approximately 2:1. The same effect occurred, with some departure, for other ratios of transposition.

The question arises whether such relational determination may not also exist for phenomenal size. That is to say, it is possible that the stimulus correlate for an object's experienced size is not so much the absolute size of its image as it is the size of its image relative to the image size of a neighboring object (which may then serve as frame of reference). Certainly the absolute size of the image cannot fully account for phenomenal size since it changes with changes in the object's distance while the phenomenal size remains more or less constant.

To test the relational hypothesis it is necessary to show that size does depend on such stimulus relationships, i.e., that two retinal extents will give rise to approximately equal phenomenal sizes when these extents are in the same ratio to other components of their respective retinal patterns. The design called for is one in which the observer is confronted with two stimlus configurations, each consisting of two elements. In one configuration, the standard, the two elements remain fixed in size. In the other, the absolute size of one member is considerably different from that of the corresponding member of the first configuration and the second member is to be equated in size with the second member of the first configuration. The two configurations should be equidistant from the observer. In Fig. 3, for example, Rectangle B is three times larger than Rectangle A and Variable Line B is to be equated with Standard Line A. The prediction would then be that the variable line would have to be set to a length three times the size of the standard in order for the observer to see them as equal if the effect is complete or at least considerably larger than the standard if it is present but not complete. Experiments somewhat along this line have been performed in the past but not for the theoretical reasons here outlined (Künnapas, 1955; Obonai, 1954). They were performed to determine whether context would have an effect on size (in the sense of an optical illusion); only a very slight effect was obtained (of the order of about 5 to 10% difference in the size of the lines) (Künnapas, 1955). But there was a major reason why such experiments could not be expected to show a strong effect in terms of the thesis outlined above: they were done in full illumination. Under these conditions, each rectangle or frame of reference is seen within a common frame of reference (e.g. one wall of the room) as illustrated schematically in Fig. 4. In relation to the outermost common frame of reference, the two lines would only look equal when they were objectively equal and this would operate

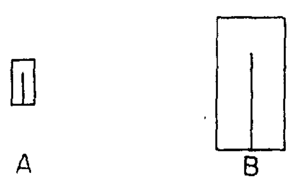

FIGURE 3.

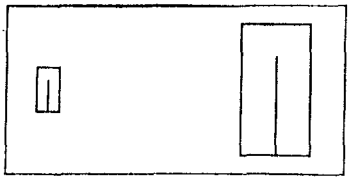

FIGURE 4.

to oppose the expected effect. Hence the experiments to be described were performed with luminous objects in total darkness just as was the case in the Wallach and Brown experiments discussed above. To eliminate a direct effect of the two configurations on one another it was also necessary to separate them in space.

Experiments 1A, B, and C

Procedure. Ten college students (five male and five female) took part in Experiment 1A. The *S* was led with eyes closed into a completely darkened room and seated exactly midway and at a distance of 5 ft. from each of two luminous rectangles having a ¼-in. luminous contour. He had to turn around 180° to look from one field to the other. The dimensions of these rectangles were 2×4 in. for the standard which appeared on the *S*'s left and 6×12 in. for the variable on his right. The smaller dimension in each rectangle served as the base. Each rectangle contained a luminous line starting at the base and running up the center.

The rectangles were produced by the application of luminous paint on black cardboard. In order to compare lengths it was necessary to have a line of variable length in one of the rectangles. This was achieved by cutting a 2 in. wide vertical slit through the center of the rectangle running from the base to the top of the luminous contour. Behind this slit was placed a strip of black cardboard upon which was painted a luminous line of desired width. This strip was then fitted with a track such that it could be moved manually, either up or down behind the luminous contour. A permanent scale of ⅛ in. intervals was placed alongside the vertical slit thus enabling the *S*'s settings to be read off directly.

In experiments where an artificial pupil was used, 8-watt ultraviolet bulbs were employed to increase the apparent luminosity of the rectangles. This was necessary because the artificial pupil severely reduced the amount of light from the rectangles reaching the eye. Where an artificial pupil was not used the ultraviolet bulbs could not be employed because the white light which they emitted would have made other objects visible under these conditions of viewing. In such experiments, therefore, the rectangles were illuminated periodically by a lamp to maintain the necessary level of brightness. In all experiments reported here wherever the luminous rectangles seemed to light up other objects in the room *S* was required to wear sunglasses. This served to keep the background completely dark.

In Part I of this experiment, the *S* was asked to equate a luminous line of variable length on his right with a standard luminous line of 3 in. length on his left when the rectangles were not yet visible. In this condition both lines were of equal width. In Part II the *S*'s task was again to equate a variable luminous line on his right with a 3 in. standard on his left. In this condition, however, the lines were presented within two luminous rectangular contours of the dimension given above, such that the rectangles were transposed in all linear dimensions in the ratio of 3:1. In order to make transposition complete, the variable line was also transposed to three times the width of the standard line. All *S*s were given one ascending and one descending trial using the method of limits. In both parts the descending trial was given with the starting position of the variable at 12 in. The *S* viewed the scene binocularly. The following instructions were read at the beginning of the experiment after a 15-min dark adaptation period.

> You may now open your eyes. If you look to your left and then to your right you will find a luminous line in each direction. I can adjust the rod on the right so that it changes its length. I want you to look to the right and tell me when it has the same length as the rod on the left. You may look back and forth as often as you like. It is important that you do not try to figure out the lengths, but try to report your spontaneous impressions. It is equally important that when you have completed your match, the lines look to you to be equal in length with respect to each other.

At the beginning of Part II, *S* was instructed as follows: "In this part of the experiment your task is exactly the same as before" and the above instructions were repeated with the following addition to the last sentence . . . "and not necessarily with respect to the frames."

Thus the instructions were formulated in such a way as to make sure that the task was clear—that *S* could not believe he was supposed to make a relational match.

Unless otherwise specified the procedure for all subsequent experiments followed the outline reported above.

By way of supplementing these data, several other experiments were performed under only slightly different conditions. Experiment 1B was identical with 1A except that prior to the matching of the lines alone the *S*s were required to match the rectangles alone (described below as Experiment 5A). Also, the observations were made monocularly, through an artificial pupil. Fourteen *S*s were used. Experiment 1C was also identical except that it was preceded by a slightly different task involving the matching of the apparent distances of the two rectangles. An additional 10 *S*s participated in this variation. In these two experiments the last line of the instructions ("and not necessarily with respect to the frames") given in Part II of Experiment 1A was deleted but care was taken to ensure that the *S*s understood the task. If *E* had any doubt, he questioned *S*.

Results. The first three rows of Table 1 summarize the results of these experiments. The next to the last column gives the ratio of the average adjustment in Part II to the 3 in. standard.

In Part I a 3 in. standard was matched on the average with a variable length of 3.1 in. ($SD = .18$) in Experiment 1A, with 3.2 in. ($SD = .17$) in 1B and with 2.9 in. ($SD = .65$) in 1C. Whereas the identical line length was matched in Part II to an average length of 6.0 in. ($SD = 1.5$), 6.6 in. ($SD = 2.0$), and 6.8 in. ($SD = 1.7$) for Experiments 1A, B, and C.

These experiments indicate that under conditions where it is perfectly feasible to perceive lengths accurately on the basis of their actual size, the presence of the surrounding rectangles yields a very strong relational effect. The average variable setting is well over twice as long as the standard.

Experiment 2

In this experiment the order of Parts I and II was reversed. Although there can be no question that the *S*s understood the instructions, the variable line in the large rectangle was now adjusted, on the average, to 7.2 in. ($SD = 1.2$) ($N = 9$). Without the rectangles present the variable line was set on the average at 3.7 in. ($SD = .66$). This setting is at a distance of approximately three times the standard error of the mean from 3.0 and thus reveals a very interesting after-effect of the adjustment in Part I. When the rectangles were present the image of the variable line was objectively larger than that of the standard when the lines appeared equal, and apparently as a result there was some tendency to continue in this direction even when the frames of reference were absent. This finding suggests that a reverse effect may have occurred in the several variations of Experiment 1, namely, an aftereffect of absolutely equal image sizes operating to oppose the transposition effect. From this point of view, one might argue that the results of Experiment 2 should be given added weight as perhaps the least biased measure of the effect under investigation (hence in all subsequent experiments Part II was given first). Using the 3 in. standard as a base, the average variable setting yields a ratio of 2.4. In other words the *S*s experience the two lines as equal when one is objectively 2.4 times larger than the other.

Experiment 3

There is one minor flaw in the experiments described above. It will be recalled that the variable line was itself transposed, such that its width was

TABLE 1

SETTINGS IN INCHES IN EXPERIMENTS 1–4

(Standard = 3 in.)[a]

Experiment	Condition	Without Rectangles		With Rectangles		Ratio Variable/ Standard	N
		M	SD	M	SD		
1A	15 min. adaptation; binocular vision	3.1	.18	6.0	1.5	2.0	10
1B	Prior task; artificial pupil	3.2	.17	6.6	2.0	2.2	14
1C	Prior task; artificial pupil	2.9 (N = 6)[b]	.65	6.8	1.7	2.3	10
2	Order reversed; binocular vision	3.7	.66	7.2	1.2	2.4	9
3	Width of line varied; binocular vision			6.7	1.6	2.2	14
4A	Triangles; binocular vision	3.3 (N = 10)[c]	.62	5.2	.88	1.7	10
4B	Circles, in squares; binocular vision; standard = 1 in.	1.1 (N = 8)[c]	.19	2.0	.79	2.0	10

[a] In Experiment 4B the standard was a circle of 1 in. diameter.
[b] Only 6 of the 10 *Ss* participated in this condition.
[c] Separate *Ss* were employed for these conditions.

three times that of the standard line. This was done so that all dimensions would be transposed. But this means that if *S* were to try to match the lines when they are absolutely equal in length the difference in widths would work against such a match.

The procedure was, therefore, modified so that the variable line always preserved the proportions of the standard line. This was accomplished by presenting *S* with a series of variable lines in 1 in. steps, from 2 in. to 10 in., in ascending or descending order. Cardboard strips containing the luminous lines were inserted in a carboard slot fixed to the front surface of the variable rectangle. In this procedure the 3 in. line was therefore identical in every respect to the standard, thus meeting the above objection. The result, for the line-in-frame condition only, does not differ appreciably from that of Experiment 2. For 14 *Ss* the mean setting was 6.7 in. ($SD = 1.6$).

Experiment 4A

The foregoing experiments all employ a line figure as the critical object. To explore the effect for objects which appear phenomenally more two-dimensional, the above procedure was employed using triangles as the objects to be compared. The standard triangle in the small 2×4 in. rectangle was 3 in. high with a 1½ in. base formed by the bottom line of the rectangle. The entire area enclosed by the triangle was luminous. The variable triangle in the large 6×12 in. rectangle was similarly constructed, but was larger such that it could be brought up from the base to any desired height. The triangle was placed behind the luminous rectangle, the inside of which was cut away. The triangle disappeared below the base of the rectangle as it was made smaller. Thus as it was moved up or down its over-all shape remained constant and similar to that of the standard. In this respect the procedure is similar to that of Experiment 3. Ten *S*s were employed in this variation. The average setting was 5.2 in. ($SD = .88$). A separate group of 10 *S*s was required to match the triangles in the absence of the rectangles. The mean setting was 3.3 in. ($SD = .62$).

Experiment 4B

A similar procedure was employed using luminous outline circles in squares. The standard was a 1 in. diam. circle in the center of a 4 × 4 in. square. The variable circles appeared in a 12 × 12 in. square and were placed one by one in the center of the square in 5 steps from .5 in. to 4 in. in diameter, in ascending or descending order. The luminous circumference of the circles was approximately ⅛ in. thick. Ten *S*s partook in this variation. The mean setting was 2.0 ($SD = .79$). A separate group of 8 *S*s was given the task of equating the circles without the squares present. As in the previous experiments, this task was accomplished with considerable accuracy and consistency, the mean setting being 1.1 ($SD = .19$).

The results for 4A and 4B are somewhat lower than those for the line in otherwise comparable experiments. A possible explanation for this difference is that the triangles and circles are two-dimensional figures which, therefore, differ considerably in area when their linear dimensions differ to even a slight extent. When, for example, the heights of the two triangles are in the ratio of 2 : 1, their areas are in the ratio of 4 : 1. Figure 5 illustrates this relationship. The areal change occurs for the line figures too but seems not to exert a psychological effect—phenomenally they appear as more or less one-dimensional.

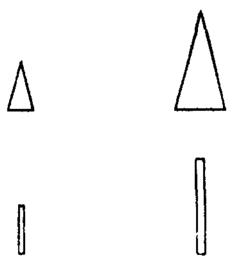

FIGURE 5.

The question arises whether the observer perceived the two rectangles to be equidistant from himself. If for any reason the small rectangle was seen as farther away—if for example it was seen as three times as far as the large rectangle—we would expect it to appear to be about the same size as the large one on the basis of the traditional explanation of size constancy, namely, taking distance into account. This is the case because a rectangle equal in size to the large one, but three times as far, would also yield an image ⅓ the size of the near one. In that event the results we obtained would not be very surprising. If the smaller rectangle were seen as equal in size to the large rectangle then naturally an observer would regard the inner forms as equal when they were both proportional in length to their corresponding rectangles. It was for this reason that we required *S* to view the rectangles binocularly in the majority of the experiments, thus hoping to ensure fairly accurate distance perception. (In Experiments 1B and 1C and other experiments we also obtained measurements under conditions of monocular vision through an artificial pupil, thereby eliminating all physiological cues to distance. Since the results were not too different from those for binocular vision they will not be discussed further.)

But it might be argued that notwithstanding the use of binocular vision, which ordinarily would allow fairly accurate distance perception, there was a factor operating which might create the impression that the small rectangle was farther away, namely what has been called the relative size cue to distance. Two objects of similar shapes but of different sizes may create the impression of two equal sized objects at different distances. This happens in the case of the images of objects in a perspective scene and has a strong effect in drawings and photographs. It is possible that this cue outweighed the binocular cues. In order to rule out such an explanation the following two experiments were performed.

Experiment 5A

The rationale for the first experiment is as follows. If it were true that in the previous experiments the small rectangle looked farther away, and hence as large as or almost as large as the big rectangle, then when the rectangles themselves are compared this fact should be revealed. *S*s should equate the two rectangles in size when in actual fact they are quite unequal. In fact they should consider them as equal at or close to the starting size. It is important to be clear that the objection is not merely that the small rectangle appears to be farther away but that *it appears to be about equal in size to the large one because it appears farther away.*

The most obvious way of testing this deduction is to require the *S* to equate the sizes of the rectangles, varying the size of one until he considers them equal. We performed such an experiment and found that the *S*s were able to make quite accurate matches, thus suggesting that the rectangles did not at all appear equal or even nearly equal at the outset. There is, however, a flaw in this design. Suppose at the outset the smaller rectangle appears to be only about twice as far as the larger one. It will therefore appear to be about two thirds the size of the large one. (Such a partial distance effect could indeed explain our findings since only partial transposition was achieved.) The *S* would then require the variable rectangle to be changed slightly. Once this change is made, however, *S* is now confronted with a new relative-size cue to distance. On the basis of this he may again request a further size adjustment, and so on. Eventually this could also lead to an accurate match.

To get around this difficulty the experiment was revised as follows.

Procedure. After first comparing the two rectangles *S* was required to make his match from memory without further reference to the standard, which was then hidden from view. This procedure eliminates the problem of continuously changing relative-size cues to distance.

Ten college students were employed. Again the rectangles were separated from one another by 180° so that *S* had to turn his head from one to the other and the same dark room conditions prevailed. At the outset the *S* was shown the two rectangles in the size ratio of 3:1 as in the previous experiments, with the major difference that the vertical lines were not present. As in the previous experiments *S* was again at a distance of 5 ft. from each rectangle. The larger rectangle was now so constructed that its size could be varied (the top and right side formed one unit which extended in back of the bottom and left side and which could be moved diagonally upward or downward). *S* viewed the rectangles binocularly. He was told he would be asked to give his impression of the relative size of the rectangles and was given adequate opportunity to compare them with one another. Following that the standard was blocked from view and *S* proceeded to equate the variable to the size of the standard from immediate memory. He did not see the variable rectangle during the period its size was being altered.

For the decending condition the standard rectangle was 2×4 in. For the ascending condition the standard was 3×6 in. The variable rectangle was first set as larger than the standard (6×12 in.) for the descending condition and reduced in size. For the ascending condition it was first set as smaller than the standard (1×2 in.) and increased in size. For half the *S*s the ascending condition was given first and for the other half the order was reversed. Before the second condition *S* was given an additional view of both rectangles. If there is any tendency at all to see the rectangle which is smaller as farther away, and, therefore, closer in size to the other rectangle the average setting of the variable should be considerably smaller than the standard in the ascending condition and considerably larger in the descending condition.

Results. The results shown in Table 2 were quite clear. The *S*s were able to equate the two rectangles with considerable accuracy. With the standard measuring 4 in. in height for the descending condition, the variable was set on the average at a height of 5.1; with the standard measuring 6 in., for the ascending condition, the variable was set on the average at 6.5 in. In both cases there was a slight tendency toward overestimating. The ascending average was in the direction opposite to that predicted by the hypothesis being tested. Thus it must be concluded that in the earlier experiments either the smaller rectangle did not appear to be appreciably farther away, or if it did, its apparent distance did not affect its size to any substantial extent.

Experiment 5B

As a matter of fact, in a further experiment it was possible to test directly the question of a distance effect. Again the observer was confronted at the outset with the two different sized rectangles as in Experiments 1–4, each at 5 ft. The larger one was now set on a track and the observer was required to indicate when it appeared equidistant with the smaller one (here using binocular vision). As in Experiment 5A *S* was not allowed to view the two rectangles together once

TABLE 2

MEAN SETTINGS OF HEIGHT OF RECTANGLES IN EXPERIMENT 5A

	Total Ascending (6 in. Standard)	Total Descending (4 in. Standard)	Ascending of *S*s given ascending first	Descending of *S*s given descending first
M	6.5	5.1	6.6	4.4
SD	.36	.63	.82	.40
N	10	10	5	5

he began making his match. Two matches were made by each *S* but they were both of necessity descending trials, i.e. the large rectangle was moved away from *S* in both cases. The average setting was at 5.6 ft. for 7 *S*s excluding one who saw no difference and two who saw the larger rectangle as farther away. On the average, then, the larger rectangle appeared only slightly nearer than the smaller one.[8]

Returning to the main findings, an important question arises at this point. The results show that to a very considerable extent size is determined relationally. Yet the average setting of the variable stimulus falls short of the value required for complete proportionality. What factor (or factors) opposes relational determination?

It is always possible to argue that we did not achieve complete darkness and that, therefore, to some extent a common frame of reference was present. If true it would be expected to oppose a proportionality outcome as noted earlier. We did perform an experiment similar to those reported above using lines, but with the room lights on. The ratio than dropped to

[8] The absence of a marked effect of the relative-size cue in this experiment is probably due to the fact that the two rectangles are 180° apart with respect to the *S*. Ordinarily when this cue is effective the objects are more or less adjacent to one another.

1.3 : 1, so there is no question that a common frame would have a deleterious effect. But the fact is that great pains were taken to ensure total darkness in these experiments and a careful inspection by two observers failed to reveal any visible objects other than the luminous objects proper.

More probably, relational determination is not complete here because the size of the inner objects *relative to one another* is at least to some extent still perceptible in spite of their being surrounded by their respective rectangles and separated from one another spatially. The results of the figures-alone matches show clearly that in the absence of the rectangle the figures can be equated to one another with considerable accuracy. This being the case, the magnitude of the departure from objective equality with the rectangles present must be considered as an impressive example of what Duncker (1929) has described as separation of system, albeit a separation which is not complete. A relational match also implies that *S* must ignore the logical contradiction that objects proportional to rectangles which themselves are perceived as quite unequal cannot be equal to one another.

If it is correct that the size of the inner objects relative to one another is to some extent still perceptible, it would follow that for transposition ratios greater than 3 : 1 there would be a falling off of the relational effect. As transposition ratios are increased, the relative sizes of the enclosed lines must diverge more and more from absolute equality in order to yield relational matches. For example a 5 : 1 ratio would require one object to be set to a size five times the size of the other. Although a strong tendency in this direction might exist it would be opposed by the very great absolute size difference required. Conversely it follows that for a ratio less than 3 : 1 the relational effect would increase because the observer would only have to tolerate a smaller absolute difference.

TABLE 3

	Transposition Ratio			
	2 : 1	3 : 1	5 : 1	8 : 1
N	10	14	10	10
M	6.4	6.7	6.6	6.2
SD	.30	1.6	1.0	1.0
Standard	4	3	3	1.8
Ratio	1.6	2.2	2.2	3.4
% Complete	80%	73%	44%	42.5%

Experiment 6A, B, and C

The procedure of Experiment 3 was followed in all respects except for the difference in the sizes of the two rectangles. In Experiment 6A the smaller rectangle was 3 × 6 in. and the larger one was 6 × 12 in., thus yielding a ratio of 2 : 1. In Experiment 6B the smaller rectangle was 2 × 4 in. and the larger one was 10 × 20 in., thus yielding a ratio of 5 : 1. In Experiment 6C the smaller rectangle was 1.2 ×2.4 in. and the larger one was 9.6 × 19.2 in., thus yielding a ratio of 8 : 1.

The results together with those of Experiments 3 for the 3 : 1 ratio are shown in Table 3.

The results show that as the transposition of dimensions increases, the ratio of the variable setting to the size of the standard increases. For the 8 : 1 transposition the variable line is set on the average at 3.4 times the size of the standard. This is a very impressive relational effect. Nevertheless it is true that in comparison with what would be complete transposition there is a falling off of the effect.[4] Hence

[4] In the transposition of velocity, Brown (1931) found a less than complete effect for fields transposed in the ratio of 2 : 1 and a falling off of the effect with fields trans-

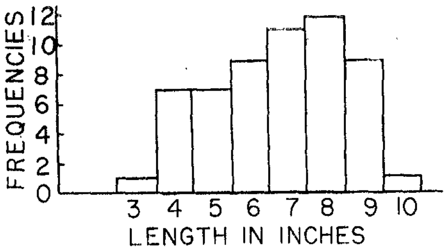

FIG. 6. Length in inches of variable setting of line matched to the 3 in. standard.

these results support the view that it is the impression of the size of the inner objects relative to one another which opposes the relational effect.[5] Separation of system is not complete.

There were, however, large individual differences. For example in Experiments 1A, B, C, 2, and 3 close to half the sample tested gave complete or nearly complete proportional matches and others gave matches closer to objective equality. Figure 6 shows the distribution of matches for all *S*s combined in these five experiments. These differences no doubt reflect the way in which *S*s resolved the conflict between the relational effect and the impression of the size of the inner objects to one another.[6] Individual consistency was, however, very high. The correlation between ascending and descending trials for the *S*s in these five experiments was .93.

One of the major implications of the relational basis of achromatic color and speed perception is that it offers an explanation of achromatic color and speed constancy (Wallach: 1939, 1948). When in daily life the illumination changes it almost always affects all neighboring regions equally. Since the *ratio* of reflectances is not changed thereby, there is no reason to expect the experienced color to change if it is true that achromatic color depends upon the ratio of reflectances. Similarly when a moving object is viewed at varying distances its rate of displacement relative to some frame of reference (a car passing along a road in front of a row of trees for example) does not change. If phenomenal speed depends on rate of relative displacement as Brown has shown—and a change in distance only brings about a transposition on the retina of all the dimensions of the scene—there is no reason to expect any change to occur with variations in distance.

Now that we have been able to demonstrate a rather strong relational determination of phenomenal size it is plausible, therefore, to inquire whether this can account for size constancy. When we see an object next to some other object of a different size, one which we might say serves as a frame

posed in greater ratios. However in absolute terms the transposition of velocity is more nearly complete than is the transposition of size.

There are several possible ways of explaining the superiority of transposition of velocity. Duncker's (1929) work leads to the conclusion that movement is itself relationally determined and movement is the quality of which speed (rate of movement) is the quantitative aspect. But extensity—of which size is the quantitative aspect—is not relationally determined. Furthermore the perceived discrepancy in the *size* of the two rectangles is bound to be more disturbing to the relational determination of the *size* of figures than to the *speed* of figures—i.e., size can be compared with size more directly than with speed. Finally it might be easier to compare the sizes of figures without rectangles present than the speed of objects, and this being the case the absolute comparison might also obtrude itself more in the case of size than of speed.

[5] The poorer results with the two-dimensional figures also support this view because the absolute size-differences were more obtrusive.

[6] Females showed a slight tendency toward higher settings than males, namely 6.8 in. vs. 6.4 in. in the same five experiments cited above. The difference, however, falls short of significance.

of reference, the ratio of the two sizes to one another and, therefore, of their respective image sizes would remain constant with changes of distance. To the extent that phenomenal size is dependent not upon the absolute size of the image but on its size relative to another object, size constancy would follow as a matter of course, at least in many situations in daily life.

This explanation is quite different in its implications from the traditional one that distance is somehow "taken into account." The essence of this explanation as with those of Wallach is in the specification of certain invariant properties of the stimulus which can be correlated with the perceptual experience in question (size, color, speed) even when the vitiating factor (change of distance, change of illumination) operates. Thus it would no longer be correct to say that the perceptual experience in the case of a given constancy is not in perfect correspondence with the stimulus. It is only not in correspondence with that aspect of the stimulus which previously was thought to be the relevant one (size of the image, intensity of the image of the object alone, absolute rate of retinal displacement).

Another implication of the relational explanation is that it would seem to make the assumption of learning gratuitous. If we can point to an attribute or dimension of the stimulus which always corresponds with a given experience then it is no more necessary to argue that these constancies are learned than it is to argue that the dependency of hue on wave length is learned. The constancies discussed above follow as a matter of course from the very stimulus conditions which have been discovered to underlie the experienced attributes in question (size, achromatic color, speed.[7] A further implication of this type of explanation is that the constancies are truly sensory in character and are not merely intellectual elaborations of underlying sensations.

It is perhaps worth noting in passing that these solutions are compatible not only with Gestalt theory but also with other points of view such as that of Gibson (1950). Since they represent instances where relational stimulation underlies perceptual experience it is implied that the neural correlate involves central interaction processes. However one may merely prefer to say, as would Gibson, that these are precisely the kind of higher order stimulus attributes we should expect to find as the correlates of particular perceptual experiences.

But there are a number of considerations which suggest that in the case of size constancy the relational explanation is not sufficient. Unlike the case of achromatic color—where the determination by ratio is all but perfect —and the case of speed—where the transposition effect is sufficiently large to account for speed constancy—the transposition effect for size is far from complete as noted above. Yet size constancy is more or less perfect within a considerable range of distances. Certainly in many situations in daily life involving objects at distances from the observer in the ratio of say, 3 : 1, size constancy is complete. (At these distances the images of the two patterns would be transposed in the ratio of 3 : 1 and for this ratio the relational effect is not complete.) At least we can say that in experiments in which the observer is to equate sizes of ob-

[7] Nevertheless, in spite of this reasoning it is still possible that the judgment of size on the basis of stimulus relationships such as we have shown to exist may in point of fact be the result of learning.

jects at these relative distances, the results will show approximately perfect constancy unless very great absolute distances are involved. It may be argued, however, that in this situation the observer is oriented to give the "correct" answer more than he is to give a careful phenomenological description of what he *sees*. Hence to some extent he may *perceive* the distant object as at least somewhat smaller than the near one but *judge* it as equal —and to that extent Helmholtz would be correct.[8] This same objective attitude of the observer would in our situation, however, operate to reduce the relational effect.

There is no doubt some truth in this reasoning, but its importance should not be exaggerated, because when one encourages the observer to try to match in terms of visual impression instead of judgment of true size, the results are not very much different (except perhaps at great distances where there does appear to be a falling off of constancy). A more probable explanation of the fact that constancy is better than could be predicted on the basis of our results is that relational determination is not the only factor operating. It would seem necessary to admit the truth of the traditional explanation as at least one of the factors at work in size constancy for the following reason. In a completely dark room phenomenal size is not determined exclusively by visual angle relations even under conditions where an explanation in terms of a relational effect would be ruled out. A luminous object will not appear the size that its visual angle would demand when it is viewed at varying distances, e.g., it will not appear half as small at twice the distance. In short, distance is taken into account with the result that there is a tendency in the direction of constancy, and as the degree of constancy increases distance perception is better.[9]

Thus it seems possible that under ordinary circumstances both the relational factor and the taking into account of distance operate together to yield perfect or nearly perfect constancy. In the following experiment an attempt was made to examine this possibility.

Experiment 7A

Procedure. In Part I, *S* was to match a variable luminous line, at 2 ft. with a standard 3 in. line at 10 ft. in a darkened room, the two being separated by an angle of 90°. The two lines were here of equal width (.1 in.). Hence the method of Experiments 1 and 2 was used in which the length of the variable line was continuously changed. *S* was only allowed to use one eye on the assumption that this would considerably reduce the accuracy of distance perception but would not completely eliminate all cues to distance (an artificial pupil was *not* employed). Hence it was expected that the match would not be based exclusively on equality of visual angle but in-

[8] This attitude of the observer explains the apparently enigmatical fact, reported with increasing frequency during the last decade, of overconstancy, particularly at great distances. It is quite clear from the standpoint of phenomenological description that the very distant object *looks tiny*, but the experimental finding is in the opposite direction. This is what we would predict if the observer were *judging*, and in doing so, compensating for what he thinks the effect of distance is on apparent size.

[9] Recently a few psychologists have voiced their skepticism of this principle because of the fact that phenomenal size does not correlate with phenomenal distance in experiments where the observer is required to judge both (e.g. Gruber, 1954). But this conclusion is based on a premise which may be faulty. It is more likely "registered distance" as given by various cues, not "phenomenal distance," that enters into the interaction. That is, it is not essential for the distance cues to be translatable into a corresponding awareness of distance in order for them to interact with image size in yielding size constancy.

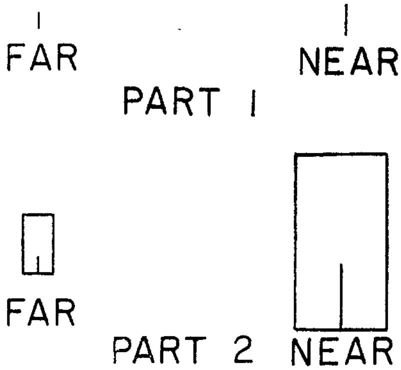

FIG. 7. The retinal situation based on the average matches in Parts I and II of Experiment 7A.

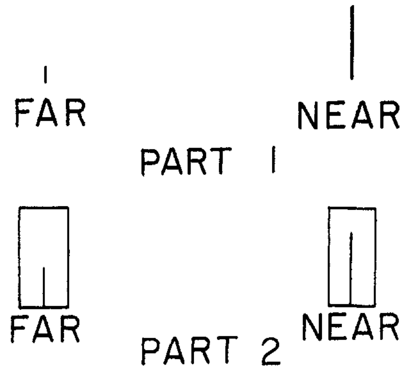

FIG. 8. The rentinal situation based on the average matches in Parts I and II of Experiment 7B.

stead would show some tendency in the direction of constancy.

In Part II, the same task was repeated except now each line was .5 in. wide and was surrounded by a luminous rectangle 6 × 12 in.

Results. In Part I, the average setting for 16 *S*s was 1.2 in. (*SD* = .34). A match based exclusively on visual angle would have required a line .6 in. in length (3 in./5 since the near line is at 1/5 the distance) whereas perfect constancy would have required a line 3 in. in length. Thus there is some slight tendency in the direction of constancy.

In Part II, the average setting was 2.7 in. (*SD* = .75) which means that here constancy was virtually complete. Since the only change was the addition of the surrounding rectangles (which of course as images were transposed in the ratio of 5:1) this increase is to be attributed to the relational effect (see Fig. 7). In this particular situation, therefore, involving only rather poor cues to distance, relational determination makes a much greater contribution to constancy than does the taking into account of distance. But the main point of this experiment is that we have shown that the relational factor does influence constancy and that when the two factors cooperate, constancy approaches completeness.

Experiment 7B

It is , of course, possible that the relational factor may interact with the distance factor in a negative sense, i.e., by yielding a nonveridical, illusory outcome. This might occur wherever the two frames of reference are objectively unequal in size. We were able to demonstrate this effect in an experiment where the lines alone at distances from the *S* in the ratio of 5:1 were first matched in the dark with *binocular* vision. This yielded perfect constancy on the average for 10 *S*s. When, however, the distant line was surrounded by a rectangle 5 times as large as the near rectangle (thus yielding equal sized images of the two rectangles), it brought the average length of its line up to 2.7 times the length of the near line (see Fig. 8).

Another problem to be considered, bearing on the applicability of our findings to size constancy, is the magnitude of the relational effect for transposition ratios other than 3:1. On the basis of the results reported above we would have to predict a falling off of size constancy as the ratio of distances between the objects compared increases — since this increases the ratio of the image patterns.

It is tempting to relate these findings to the well-known fact that size constancy does fall off at great distances. But one can easily increase the distance ratio between objects from, say, 2:1 to 8:1 without placing the far object at a very great distance and under these circumstances constancy will not decline appreciably. Furthermore one can create very much higher distance-ratios by placing the near object very close rather than the far object very far, and we have been unable to show a falling off of constancy in such a situation. In fact Jenkins (1957) recently performed such an experiment and obtained the opposite effect. However it is difficult even to demonstrate the falling off of constancy at great distances because the observer is governed by an objective attitude and not a phenomenological one in the constancy situation. This problem therefore remains open, but at the moment the facts concerning increased distance ratios do not support the relational interpretation. Perhaps the possibility of taking distance into account serves to offset the predicted decline in constancy based on the relational factor.

There are two other difficulties for the relational explanation of size constancy. One is the fact that the relational effect is smaller for figures which appear two dimensional than for the phenomenally more or less one dimensional line figures. Yet most objects in daily life present us with a two dimensional surface.

The second is that the objects we view are not necessarily always seen in front of or adjacent to a large object which can serve as a frame of reference. And even when they are, there remains the question of the constancy of size of the frame of reference itself. By frame of reference we only mean to refer to that object with respect to which the relative size of a second object can be gauged. However Duncker (1929) has shown in the case of movement that not all objects serve equally well as frames of reference, the larger, surrounding object generally fulfilling the function of that with respect to which movement is perceived to occur. Furthermore only for surrounded objects could one expect to have a strong tendency toward separation of system. We were, in fact, able to show in an experiment that when the *inner* objects were transposed in a given ratio their effect on the size of the outer rectangles was nil. This being the case the relational effect does not contribute very much to an explanation of the constancy of objects which play this role in any particular situation.

SUMMARY

By way of summary, we have shown that to a very considerable extent phenomenal size is relationally determined. The effect is greater for line figures than for those which appear as two dimensional. As the transposition of dimensions increases the ratio of the size of the variable to that of the standard increases, but, nevertheless, there is a falling off of the effect from the standpoint of complete relational determination.

We have shown that the relational effect is not an artifact based on a tendency to see the smaller frame of reference as farther away and, hence, as equal in size to the nearer one.

It would seem that the fact that the effect is not complete is due to the tendency of the observer to be influenced by the absolute sizes of the enclosed figures with respect to one another, at least to some extent.

We have considered the possibility that the relational determination of perceived size explains size constancy. Since, however, size constancy is often perfect but the transposition effect is not complete we have argued that size constancy must also be based on the taking into account of distance. In two experiments we were able to demonstrate that the relational effect *and* the taking into account of distance can both play a role in the perception of size at varying distances.

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