Psychological Bulletin
1961, Vol. 58, No. 6, 491–514

THE CURRENT STATUS OF THE SIZE-DISTANCE HYPOTHESES[1]

WILLIAM EPSTEIN, JOHN PARK, AND ALBERT CASEY
University of Kansas

In the history of the psychology of perception few matters have been of more continuous interest than the relationship between perceived size and perceived distance. It is our objective to examine the current status of this question by reviewing the recent literature. With some exceptions our review will be confined to investigations which have been reported since 1952. Several surveys of the literature prior to 1952 are available, and for this reason we will have relatively little to say about these earlier investigations (reviews can be found in Boring, 1942, Ch. 8; Vernon, 1954, Ch. 5; Woodworth & Schlosberg, 1954, Ch. 16).[2]

Most studies of this question have converged upon a single proposition which aptly has been called the Size-Distance Invariance Hypothesis. The invariance hypothesis is often stated in the following terms: "A retinal projection or visual angle of given size determines a unique ratio of apparent size to apparent distance" (Kilpatrick & Ittelson, 1953, p. 224). This proposition has been applied repeatedly in explanations of perceived size and distance in general, and in accounts of size constancy in particular.

Two variations of this fundamental proposition also have been asserted frequently. The first may be called the Known Size-Apparent Distance Hypothesis, and it can be derived directly from the more general proposition stated above. It may be expressed as follows: an object of known physical size uniquely determines the relation of the subtended visual angle to apparent distance. This hypothesis is the basis for many explanations of size as a cue for apparent distance.

The second variation is often called Emmert's Law, and in this form has been employed in investigations of the size of the afterimage and its relationship to the distance of the projection surface. Woodworth and Schlosberg have stated the relationship in this way: "the judged size of the image is proportional to the distance" (1954, p. 486). A more general statement can be formulated also: the apparent size of an object will be proportional to distance when retinal size is constant. In this form the close relationship between this proposition and the broader Size-Distance Invariance Hypothesis is obvious. We have given the proposition independent status because it has been applied mainly to questions concerned with the perceived size of the afterimage.

For clarity of exposition we have elected to review each of these propositions separately. However, the

[1] Work on this paper was supported by a grant (M-4153) to the first author from the United States Public Health Service, a grant from the General Research Fund of the University of Kansas, and a predoctoral research fellowship awarded to the second author by the United States Public Health Service.

[2] Several reviews which have appeared more recently have not added very much to the earlier treatments (see Bartley, 1958, pp. 179–187; Dember, 1960, pp. 169–192). The same can be said about the presentations contained in the recently published opthalmological textbooks. Two illustrative discussions can be found in Bedrossian (1958, pp. 109–115) and Adler (1959, pp. 762–780).

reader will discover that on several occasions we have violated these self-imposed boundaries. In the closing section of this paper we shall present some conclusions about the size-distance relationship in general.[3]

The Size-Distance Invariance Hypothesis

This hypothesis proposes an invariant relationship between perceived size and distance such that the apparent size of an object is uniquely determined by an interaction of visual angle and apparent distance.

Support for the invariance hypothesis comes from studies which show that the size of an unfamiliar object can be judged accurately only if cues to the distance of the object are available. The prototypal experiment was performed by Holway and Boring (1941), who obtained size matches under four sets of conditions which represented a successive elimination of distance cues. Size matches approximated constancy under conditions of binocular viewing and gradually approached the law of visual angle as distance cues were eliminated. However, perfect visual angle matches were not obtained even under the condition of greatest reduction. This was attributed to a "light haze" visible within the reduction tunnel due to light reflections in the corridor. When this cue was eliminated, perfect visual angle matches were obtained (Lichten & Lurie, 1950). These findings have been confirmed in more recent investigations which utilized a variety of stimulus objects and a variety of techniques for eliminating distance cues (e.g., Chalmers, 1952, 1953; Hastorf & Way, 1952; Renshaw, 1953; Zeigler & Leibowitz, 1957).

The results referred to above are usually interpreted as a straightforward demonstration of the dependence of perceived size on perceived distance. However, we wish to point out that the introduction of the visual angle matches as evidence for the size-distance hypothesis involves at least one of the following two assumptions: (*a*) under conditions of complete reduction apparent distance tends toward zero, (*b*) under conditions of complete reduction apparent distance assumes some value other than zero which is the same for both the standard and the variable stimulus.

The first assumption is untenable in its original form since the value "zero" distance is meaningless in the experimental contexts described earlier. Perhaps, then, "zero distance" might be interpreted to mean indeterminate distance, i.e., distance which is not regulated by specifiable cues. Still, as Woodworth and Schlosberg note, "we just do not perceive free-floating objects at unspecified distances" (1954, p. 481). Instead, the object will be localized at some specific distance. According to the invariance hypothesis, the apparent distance for any given observer (*O*), whatever it is, should interact with the visual angle to determine apparent size. However, since the reduced situation is ambiguous it is likely that apparent

[3] Various areas of relevant research have been omitted from this paper. Investigations dealing with the relationship between exposure time and perceived size (e.g., Allen, 1953; Comalli, 1951; Gulick & Stake, 1957; Howarth, 1951; Leibowitz, Chinetti, & Sidowsky, 1956) and the effects of relative visual direction on perceived size and distance (e.g., Gogel, 1954, 1956a, 1956b) have not been reviewed. We have also excluded reference to the developmental studies of size and distance. These investigations have been reviewed recently by Wohlwill (1960).

distance will vary for different *O*s. Under these conditions, the invariance hypothesis would predict corresponding variations in the size matches. This prediction, of course is quite different from the consistent visual angle matches obtained by Holway and Boring, etc. For these reasons the first assumption stated in terms of "zero" distance or "indeterminate" distance is not very convincing to us.

The assumption of equidistance seems more plausible. Carlson (1960a) and Wallach and McKenna (1960), addressing themselves to different aspects of the size-distance problem, have advanced the second assumption. Thus, Wallach and McKenna write that "the equation of image-sizes results from an implicit assumption of equal distance of the standard and the comparison object" (1960, p. 460). Carlson (1960a, p. 14) cites Gogel's (1956b) experiments as evidence for a tendency to see objects as equidistant under the conditions of the reduction experiment.

It is plain that a bias toward equidistance would explain the obtained visual angle matches. Unfortunately, there is little empirical basis for the contention that this tendency actually was operative. The experimental evidence for the equidistance tendency (Judd, 1898; Gogel, 1956b) was obtained when all of the objects in question were viewed simultaneously. In the classic Holway-Boring investigation the standard and comparison were viewed successively. Secondly, all of Gogel's experiments dealt with instances in which a monocularly viewed object was localized at the same distance as a *binocularly* viewed object. Gogel presented no evidence that the same equidistance tendency is present when all objects were viewed monocularly. However, the Holway-Boring results were obtained when both standard and comparison were viewed monocularly. Finally, it should be noted "that the strength of the tendency for objects to appear equidistant decreases as the lateral line-of-sight separation of the objects is increased" (Gogel, 1956b, p. 16). This fact makes it highly unlikely that the equidistance tendency was effective in the Holway-Boring type of experiment.

This analysis leads us to conclude that the applicability of the visual angle data as evidence for the invariance hypothesis involves assumptions whose validity has never been demonstrated. What is needed is a systematic experimental investigation of apparent distance under varying degrees of reduction including complete elimination of distance cues. In the absence of such information the consonance of visual angle matches with the invariance hypothesis is at best conjectural.

The frequent appeals to the invariance hypothesis in explanations of perceived size have endowed this proposition with almost axiomatic status. Nonetheless, evidence has been accumulating which casts doubt on the generality of this hypothesis. In what follows we shall describe a series of investigations whose outcomes have not been consonant with the invariance hypothesis.

Overestimation in Size Judgments

A frequently confirmed finding is size overestimation which increases with distance. As the physical distance of the object is increased, the physical size of the object is progressively overestimated. While overestimation is certainly surprising, it need not necessarily be inconsistent with the invariance hypothesis. If it should also turn out that apparent distance increases more rapidly than physical distance, then the results demonstrating increasing overestimation of size could be reconciled easily.

Let us first consider those studies which report instances of overestimation of size which increases with distance. Unless otherwise noted, the results to be described below were obtained with binocular vision and an objective matching attitude, i.e., *O* was instructed to match the standard and comparison so that they would have the same physical size. Holway and Boring (1941) found that when *O* was allowed normal binocular vision, the apparent size of a disk of light increased more rapidly with increasing physical distance than did physical size. This finding was explained as a "space error" resulting from the fact that the variable stimulus was always to the left of the standard. More recent experiments rule out this explanation. In an outdoor setting, Gibson (1947, 1950) had *O* match the size of a distant stake with the size of one of a set of nearer stakes, which stood both to the right and to the left of the more distant stake. Overestimation of the size of the distant stake increased as its distance increased from approximately 80 feet to 675 feet. The increase of estimated size with distance was greatest between 80 and 320 feet.

More recent experiments confirm Gibson's findings. Gilinsky (1955a) investigated size perception of objects presented out-of-doors at distances ranging from 100 to 4,000 feet. Size matches made under an "objective" set were greater than the physical size of the standards and increased with increasing distance of the standard. The acceleration of estimated size with distance was greatest between 100 and 400 feet. Using somewhat shorter distances and three-dimensional stimulus objects in an outdoor setting, Smith (1953) also demonstrated that apparent size increases with distance. Under Distance Condition N, the comparison was placed at 2 feet and the standard at 16, 80, or 320 feet. Under Condition R, the comparison was placed at the remote distances and the standard nearby. As the distance of the standard was increased (Condition N) the size of the comparison had to be made progressively larger than the physical size of the standard in order to achieve apparent equality. As the distance of the comparison was increased (Condition R) it had to be made increasingly smaller in order to match the standard. At distances beyond 200 feet a comparison which was smaller than the physical size of the standard was required to produce apparent equality.

Increasing overestimation of size at distances of 20 feet and less has been demonstrated by Jenkin (1957, 1959). In his first experiment, Jenkin (1957) found that when the comparison was at 2 feet, it had to be made significantly larger than when it was at 10 feet in order to match the standard at 20 feet; i.e., apparent size increased significantly over the short distance interval from 2 to 10 feet. Since the average match at the near position exceeded the physical size of the standard, and at the far position was exceedingly close to the physical size of the standard, overestimation of size is indicated. This overestimation cannot be attributed to a space error because size judgments made with the variable at the same distance as the standard were not significantly different from the true size of the standard, while the difference between true and judged size was highly significant when the standard was at 20 feet and the variable at 2.

In order to study more fully the relationship between small increments of distance and estimates of objective size, Jenkin (1959) performed a second and a third experiment, in which he presented comparison stimuli at distances intermediate between those employed in his earlier study. In the second experiment, the comparison was located at a distance of 20, 40, or 160 inches. In the third experiment, a fourth distance (80 inches) was inserted between the 40- and 160-inch positions. For all distances, mean size matches exceeded the physical size of the standard stimulus and became significantly larger as the comparison object was placed closer to *O;* i.e., overestimation of size increased with distance. The use of a third and fourth comparison distance made it possible to plot the results graphically. When plotted against the logarithms of the distances, the mean size matches gave points fitted by a straight line. According to Jenkin (1959), this straight line relationship "suggests the existence of some hitherto undiscovered law relating apparent size and short increments in distance" (p. 348).

In his first experiment Jenkin used natural lighting. Coules (1955) has demonstrated that a brighter object farther away appears to be at the same distance as a nearer but dimmer object (see also Ittelson, 1952). If the more distant stimulus objects in Jenkin's experiments received relatively less illumination than the nearer objects, then progressive distance overestimation might have resulted. This in turn would account for the progressive overestimation of size which was obtained. In order to control for differences in illumination in his second experiment, Jenkin (1959) varied the illumination of the standard stimulus between 11 foot-candles and 26.5 foot-candles, while keeping the illumination of the comparison constant at 11 foot-candles. Differences in illumination of the standard had no significant effect either on amount of overestimation of size or on the rate at which it increased with distance.

In order to determine whether increasing overestimation of size would occur with a familiar stimulus object, Jenkin (1959) permitted *O* to examine the standard at a distance of 24 inches for 5 seconds before making size matches with the standard at its usual distance of 320 inches. Increased familiarity with the standard reduced the amount by which it was overestimated but did not affect the rate at which overestimation increased with distance.

In a further experiment Jenkin (1959) tested the possibility that decreasing size matches are related to decreasing ratios of distance between standard and comparison objects. This was accomplished by placing the standard 80 inch in front of *O* instead of 320 inches as formerly. If the distance ratio is crucial, then a steady decrement in the size match should be obtained from 20 to 80 inches, and an increment in the size match should be observed at 160 inches. The data of the third experiment did not confirm this expectation. The size matches decreased as the comparison receded from 80 to 160 inches.

From the experimental evidence which we have summarized, it appears that increasing overestimation of size is well-established. The invariance hypothesis demands that increasing overestimation of size be accompanied by a tendency for apparent distance to increase more rapidly than physical distance. At least one experiment indicates that apparent distance does increase in this way: Tada (1956) performed a bisection experiment in which secondary cues to distance were eliminated. Using binocular vision, *O* made bisections by stopping one of two light spots when it appeared to be halfway between *O* and the second spot, which was fixed at a point designating the total distance to be bisected. In a second experiment, *O*'s task was to bisect a 2- or 4-meter interval, presented at various distances from *O*, with each of its end points marked by a bright spot. In both experiments, Tada found that the phenomenal midpoint was farther than the objective one. In other words, the farther half of the distance was overestimated as compared with the nearer half.

Tada's findings are given some support by Purdy and Gibson (1955). They found that when *O* was permitted full primary and secondary cues to distance, errors in dividing distances (up to 300 yards) into halves and thirds tended most frequently to involve making the nearer segment too large in comparison with the farther. However, few errors were made; in general, perceived magnitudes of distance corresponded well with physical magnitudes of distance. Consistent findings of a large acceleration of apparent size with distance would seem to demand a reasonably large and consistent tendency to overestimate the farther distance as compared with the nearer.

The invariance hypothesis is further weakened by the fact that at least two experiments on distance estimation give results exactly opposite to those of Tada (1956). Gilinsky (1951) has presented evidence which indicates that perceived distance increases with true distance at a *diminishing* rate. The experimenter (*E*) moved a pointer at a slow and nearly constant rate along the ground away from *O*, who instructed *E* to mark off successive increments of equal perceived length. In the case of one *O*, every increment of apparent distance represented an attempt to match a memorized "subjective foot rule"; in the case of the other *O*, a memorized "subjective meter stick" was being matched. For both *O*s apparent distance increased more slowly than physical distance. This experiment is defective because error in bisection experiments is related to the direction of motion of the pointer; as the pointer withdraws, *O* tends to make the farther segment too large in comparison with the nearer (Purdy & Gibson, 1955). This defect was avoided in a second experiment by Gilinsky (1951). Across a large, flat lawn, a line was stretched perpendicular to the frontal, parallel plane of *O*. *O* was required to bisect each one of 14 distances, ranging from 8 to 200 feet, by stopping a pointer, which moved back and forth along the line, at a point which appeared to be halfway between the near end of the line and a marker indicating the total distance to be bisected. The results were the same as in the previous experiment.

Smith (1958) also found that far distances tend to be underestimated in comparison with near ones. As a standard stimulus he used a white sheet of oilcloth, which was spread out on the floor of a hall. The variable stimulus was a strip of the same oilcloth rolled from a small roller. To match the length of the standard, the variable was made 15.1% longer than the standard.

The invariance hypothesis must be

abandoned if we accept both the finding of apparent distance which increases less rapidly than physical distance and the finding of increasing overestimation of size. A way out of this difficulty is suggested by Carlson (1960b), who maintains that increasing overestimation of size is an artifact of "objective" instructions. When *O* is trying to judge actual, physical size, his size matches will be influenced by his beliefs about size-distance relationships. The major attitude by which *O* will be influenced is the concept of perspective—the notion that apparent size becomes smaller as distance increases. "From *O*'s point of view, a near object must 'look' larger than a far object for the two to be equal in physical size" (Carlson, 1960b, p. 200). Hence *O* will make size matches which appear to indicate an overestimation of the far object.

Given several discriminably different distances in the same setting, amount of overestimation may be a fairly precise function of distance, but only because trials at different distances are not really independent, and *O* can judge the distances relative to each other (p. 201).

In support of his thesis, Carlson (1960b) pointed out that overestimation does not occur in experiments, such as those of Brunswik (1956, pp. 67–69) and Singer (1952), in which *O* is asked to base his size judgments upon a naive, natural impression of size ("look" instructions). Carlson (1960b) performed an experiment in which *O* was allowed, but not required to differentiate apparent visual size from objective size. Using free binocular regard, *O* adjusted a 10-foot distant variable triangle to match a 40-foot distant standard. *O* was also required to bisect the distance to the apparatus on which the standard triangle had been presented. Under apparent size instructions, size matches were accurate. Under objective size instructions, overestimation of size occurred. We are told that under both "look" and "objective" instructions, "the half-distance of the standard was . . . overestimated" (p. 206). Apparently this means that *O*, in bisecting the distance to the standard's apparatus, required the marker to be placed too close to himself. If so, the results indicate that apparent distance increases less rapidly than physical distance.

It is doubtful that Carlson has removed the difficulties facing the invariance hypothesis. Carlson (1960b) used only one pair of distances; if either the standard or the variable had been placed at more than one distance, he might have found that estimated size increases with distance under "look" instructions, even though overestimation does not occur. The published data of Brunswik (1956, pp. 67–69) and of Singer (1952) do not provide an answer to this question. Furthermore, Carlson's finding that size is accurately estimated does not match his finding that apparent distance increases less rapidly than physical distance.

Instead of linearly increasing overestimation of size, some investigators have reported a curvilinear relationship between physical distance and overestimation of size. Hastorf and Way (1952) found that when distance cues are available, overestimation of size increases from 10 to 20 feet and decreases from 20 to 30 feet. Chalmers (1952) found that overestimation increased from 10 to 20 feet and decreased from 20 to 50 feet when *O* viewed the 10-foot comparison binocularly.

It should be noted that even if the reported instances of progressive overestimation of size should be accounted for by progressive overestimation of distance this would still leave unexplained the curvilinear size distance relationship obtained by several investigators.

Nonmatching Judgments of Size and Distance

According to the invariance hypothesis, the perceived size of an object is proportional to its perceived distance, when its retinal image size is held constant. This requirement of proportionality is frequently not met when size and distance judgments are both made in the same experimental setting. For purposes of exposition, we may divide the experiments which produce nonproportional results into two classes: (*a*) In the first class are included those experiments which provide evidence for a "size-distance paradox"—a consistent tendency either to couple an underestimation of the relative size of an object with an overestimation of its relative distance or to couple an overestimation of the relative size of an object with an underestimation of its relative distance. (*b*) In the second class are those experiments which show that a variable having a consistent influence on size judgments has no consistent influence on distance judgments, and, correlatively, those experiments which show that a variable having a consistent influence on distance judgments has no consistent influence on size judgments.

Class 1: The Size-Distance Paradox. A striking example of the size-distance paradox is the moon illusion. As is well known, the moon appears larger on the horizon than at the zenith. According to the invariance hypothesis, it should also look farther away. Yet *O* usually reports that the moon looks closer when it is low in the sky. The most recent discussion of this time honored problem is by Kaufman and Rock (1960).

More detailed evidence for the size-distance paradox is provided in an experiment by Gruber (1954). The standard stimulus was a triangle which was alternately 10 and 15 centimeters in height. To the right of the standard was a variably sized triangle. This variable triangle was placed at six distances ranging from 200 to 450 centimeters. For each distance *O* made four kinds of judgments, all of them under "look" instructions:

1. *O* set the variable-size triangle so that it appeared equal in size to the standard (*a*) when the standard was half as far from *O* as the variable, and (*b*) when both stimulus objects were equidistant from *O*.

2. *O* adjusted the distance of the standard so that it appeared (*a*) half as distant as the variable, and (*b*) equidistant with the variable.

The results were all contradictory to the invariance hypothesis:

1. By setting the size of the variable significantly larger than the actual size of the standard in the size constancy matches (judgments of Type 1*a*), *O*s exhibited a mean *overestimation* of the relative size of the standard. However, a mean *underestimation* of the relative distance of the standard occurred; *O* set the standard sized triangle too far away in the half-distance judgments.

2. "Analysis of individual differences revealed no correlation between size and distance judgments." (Gruber, 1954, p. 426).

3. As the physical distance of the farther object increased, the mean constant error in size constancy matches rose from 4% to 23%, whereas the mean constant error in half-distance judgments did not vary progressively with absolute distance, fluctuating around 17%.

4. The mean errors in the control judgments (1*b* and 2*b*) were not large enough to account for the magnitude of the errors in the size

constancy and half-distance judgments.

By means of her size-distance equations, Gilinsky (1955b) attempted to show that Gruber's data are properly interpreted as supporting rather than rejecting the hypothesis that perceived size is proportional to perceived distance. However, Gruber (1956) has pointed out that Gilinsky's analysis does not apply to his most interesting result, the Finding 1 above that an object which is consistently overestimated in size is consistently underestimated in distance. Gilinsky's analysis deals only with Finding 3, and in order to do so, it must make use of a number of somewhat arbitrary assumptions.

Jenkin and Hyman (1959) report that when *O*s are given an "objective" set, Gruber's finding of a size-distance paradox is confirmed. Size judgments were obtained under four different distance conditions: (*a*) comparison 30 feet and standard 15 feet from *O*, (*b*) comparison 30 feet and standard 2 feet from *O*, (*c*) comparison 15 feet and standard 1 foot from *O*, and (*d*) comparison 15 feet and standard 15 feet from *O*. *O* made size judgments under two different instructions: to match for physical size, and to match for retinal image size. Following the size judgments, the black mounting-board upon which the variable had appeared was placed 30 feet from *O*, who was required to make estimates (in feet) of this distance. Under objective instructions, *O*s either judged the variable as relatively small and its mounting as relatively remote, or as relatively large and its mounting as relatively near.

> The relationship of analytic size-judgments to estimated distance was toward the distant object being regarded as relatively large and relatively remote, or relatively small and relatively near (p. 73).

Thus we have the paradoxical result that an *O* who is set to judge physical size responds as if he were ignoring the simple geometrical help which would come from taking distance into account, while a person who is deliberately trying to ignore distance in order to get retinal image matches responds as if he were taking distance into account. Assuming that the analytic judgments represented *O*'s best attempt to respond in terms of retinal image size, and assuming that objective size judgments represent perceived size, the invariance hypothesis demands, for any given distance, a positive correlation between analytic size judgments and objective size judgments. Such a correlation was not found.

Heinemann, Tulving, and Nachmias (1959) obtained nonmatching size and distance judgments in an experimental situation in which *O* was permitted only primary, monocular cues to distance. When distance judgments were being made, the comparison was held constant at 1° and *O* reported which of two successively presented disks, standard or comparison, was farther away. When judging the relative distance of a standard and a variable, most *O*s said that the objectively nearer disk was farther away. Since the far object looked nearer than the near object (which subtended the same retinal angle), it should have been judged as smaller than the near object, if the invariance hypothesis is true. Yet size matches were consistently "in the direction of size constancy"; the farther away an object was, the larger it was judged as being.

Kilpatrick and Ittelson (1953) have drawn attention to two phenomena of accommodation which involve a size-distance paradox. They cite Aubert's finding that partial paralysis of accommodation produces both a reduction in the apparent size of an object and an increase in its apparent distance. They also report von Kries' observation that an object appears to diminish in size and also to recede when O shifts fixation from that object to one closer by. However, both these findings are complicated by the fact that changes in accommodation involve changes in retinal image size (e.g., Pascal, 1952).

Nonproportional Results of Class 2. A number of studies indicate that when visual angle is constant, changes in apparent size are not consistently accompanied by changes in apparent distance, and changes in apparent distance are not consistently accompanied by changes in apparent size. Beginning with the classic experiments of Wheatstone and Judd, it has been frequently found that increases in convergence are regularly accompanied by decreases in apparent size. Insofar as the decrease in retinal image size accompanying convergent accommodation is not sufficient to account for the obtained decrease in apparent size, the invariance hypothesis requires that the decrease in apparent size be accompanied by a decrease in apparent distance. Yet the obtained changes in apparent distance are equivocal. This result was corroborated recently by Hermans (1954), who used a telestereoscope to produce six changes in convergence from 0 to 10°. As degree of convergence increased, the mean apparent size of the standard, as determined by *O*'s adjustment of a variable, decreased significantly. Verbal reports indicated that some *O*s perceived a decrease in distance with increasing convergence, while other *O*s perceived an increase in distance.

Kilpatrick and Ittelson (1953) found that an illusory movement in depth was not accompanied by the required change in apparent size. The trapezoidal window was suspended in *O*'s line of sight, so that its sides were vertical and the physically larger end of the trapezoid was farther from O than the smaller end. An ordinary playing card and a piece of cotton were successively moved through an opening in the window by means of a thread stretched at right angles to the line of sight. Objects carried through the trapezoid in a straight path by the moving thread appear to move through an S shaped path in the horizontal plane. In the majority of observation trials, *O*s perceived definite movement in depth of 2 feet. Yet for the largest number of trials on which movement in depth was perceived, no size changes were reported either for the playing card or for the cotton. On the remaining trials on which movement in depth was reported, size changes in a direction opposite to that required by the invariance hypothesis were reported about half as frequently as changes in the required direction. In a second experiment, an ordinary sized playing card was suspended from each of the two stationary wires by means of which the trapezoid was hung from the ceiling. On 19 trials *O*s perceived one card to be larger than the other. But on only 10 of these 19 trials did *O*s perceive the apparently larger card to be farther away, as required by the invariance hypothesis.

According to the invariance hypothesis, an improvement in *O*'s ability to estimate the distance of an unfamiliar object should result in an improvement in his ability to estimate its size. Using a series of photographs of the Gibson size-at-a-distance set-up (described above), Gibson and Smith (1952) found that training in estimation of the distances of the stakes in the photographs significantly improved O's accuracy in estimating these distances. However, there was no significant improvement in O's ability to estimate the sizes of the stakes.

Another finding contrary to the invariance hypothesis involves the visual tau effect (cf. Geldreich, 1934). Kilpatrick and Ittelson (1953) note that the difference in the perceived lateral separation of the points is not accompanied by any change in the apparent distance of the pairs of points from O.

Matching Judgments of Size and Distance. We have seen that most experiments which obtain size and distance judgments in the same setting provide evidence against the invariance hypothesis. However, in two experiments in which convergence provided the chief distance cue, matching size and distance judgments were obtained.

Bleything (1957) used a stereoprojector to cast two ring targets onto a screen. Observer and projector were equipped with polaroid filters making it possible for one ring to be seen with one eye only and the other ring to be seen with the other eye only. O saw a single fused ring which appeared to approach and recede in depth as E varied the distance between the center of the projected rings. As required by the invariance hypothesis, the apparent size of the fused ring increased with apparent distance, although the perceived size of the ring increased at a slightly greater rate than predicted by the formula, $s = (a)(d)$.

Roelofs and Zeeman (1957) report that when retinal image size is constant, a number of variables which affect apparent size also produce a complementary change in apparent distance. Two series of figures were presented. In the first series each card bore six figures: two pairs of equal sized circles which were fused binocularly (orthoptically) to give two perceived circles, and two circles which were presented either to the right or left eye alone. For the first series, Roelofs and Zeeman report the following findings:

1. Of the two circles seen binocularly, the one which required the greater convergence always appeared smaller. As required by the invariance hypothesis, it also always appeared closer to O.

2. The apparent size of the circles seen monocularly tended to be intermediate between the apparent sizes of the two circles seen binocularly. Matching this, the apparent distance of the monocularly seen circles tended to be intermediate between the apparent distances of the binocularly seen circles.

3. For a given card, the apparent size of a monocularly seen circle was closer to the apparent size of the binocularly seen circle from which it had the smallest physical separation on the card. As required, the apparent distance of the monocularly seen circle was also closer to the apparent distance of the nearby, binocularly seen circle.

4. The apparent size of the circles seen monocularly was just as strongly influenced by the circles seen binocularly with a weaker convergence as by the circles seen binocularly with a stronger convergence. However, the apparent distance was more strongly influenced by the circles seen with a stronger convergence. This is the only general finding of Roelofs and Zeeman which contradicts the invariance hypothesis.

5. Monocularly seen circles in the

lower half of the stimulus card tended to be perceived as smaller than and, matching this, as nearer than monocularly seen circles in the upper half of the card.

6. Monocularly seen circles in the nasal position tended to be seen as smaller than and as closer than monocularly seen circles in the temporal position.

7. Monocularly seen circles in the left half of the optic field tended to be seen as smaller than and as closer than monocularly seen circles in the right half of the field.

The second series of stimulus cards used by Roelofs and Zeeman had three equal sized circles: a single circle which was presented to one eye only and a pair of circles which were fused binocularly to give a single perceived circle. For the second series, the apparent size of the circles seen binocularly was greater than the apparent size of the circles seen monocularly. Matching this, the apparent distance of the binocular circles was greater than the apparent distance of the monocular circles. The findings obtained with the earlier stimulus series were corroborated with respect to the effects on apparent size and distance of nasal vs. temporal, right vs. left, and higher vs. lower stimulus positions.

Although the general findings of Roelofs and Zeeman are in accord with the invariance hypothesis, there were some individual exceptions to the required matching of size and distance judgments for all findings except the first.

In at least one respect, the experiments of Bleything (1957) and of Roelofs and Zeeman (1957) provide a fairer test of the invariance hypothesis than do the experiments which produce nonmatching judgments. Bleything, and Roelofs and Zeeman had *O* estimate the size and distance of the stimulus almost *simultaneously.* In the other experiments a relatively long temporal interval separated the estimations. It is possible that when *O* is asked to make adjustments of size (distance), his perception of size (distance) occupies the center of attention, and his perception of distance (size) is relegated to the background. The perception of both size and distance when they are merely registered as background may differ from their perception when they occupy the observer's close attention. Hence, when *O* is set to perceive size and distance at the same time, it is more likely that his judgments will match as required by the invariance hypothesis than when he is set to perceive only size or distance and not both.

Despite the methodological reservations mentioned immediately above there is sufficient cause for concluding that all is not well with the traditional formulation of the size-distance relationship. It remains to be seen whether the generally accepted invariance hypothesis can by any means be reconciled with the contradictory findings described in this section. In the eventuality that this reconciliation will prove impossible, then the way is open for a restatement of the size-distance relationship. It is also possible that in certain instances size and distance perception are unrelated. Despite their temporal co-occurrence these two experiences may be independent but simultaneous responses to separate aspects of the proximal stimulus situation. Some experimental evidence that this may indeed be the case has been presented by Gruber (1954) and Epstein (in press).

THE KNOWN SIZE-APPARENT DISTANCE HYPOTHESIS

According to this hypothesis the known size of a stimulus object determines a unique relation of retinal image size to apparent distance. Two corollaries can be derived easily from this proposition:

Corollary 1. Discrete changes in the size of the retinal image of an object whose known size remains constant will be perceived as corresponding changes in the apparent distance of that object.

Every identified object may be said to possess an "assumed size." This term refers to "the entirely subjective sense of size which the observer might relate to a specifically characterized physiological stimulus-pattern" (Hastorf, 1950, p. 195). The second corollary deals with assumed size.

Corollary 2. Changes in the assumed size of an object whose retinal size remains constant will result in appropriate changes in the apparent distance of that object.

Corollary 1

Most of the investigations which have been reported are concerned with Corollary 1. An ingenious experimental test of this proposition which has been cited often was performed by Ittelson (1951). In one experiment three playing cards were presented singly to *O* under conditions of complete reduction. Each of the cards was placed at the same physical distance from *O*. The task for *O* was to adjust a comparison stimulus of familiar size, which was presented separately, until the comparison object and the standard playing card appeared to be at the same distance. The neat turn in this experiment concerns the sizes of the three cards: one was a normal sized card, all the dimensions of another one were doubled, and the dimensions of the third card were halved. Presumably, in this situation, the only cue available for the estimation of distance was retinal size which varies directly with changes in physical size when distance is constant. When known size is invariant, these changes in retinal size ought to be perceived as changes in distance and not as changes in size. The larger card should be localized at a point half way between *O* and the distance at which the normal card is perceived, and the smaller card should be localized at twice the distance of the normal card. The results for five *O*'s confirmed these expectations almost exactly (Ittelson, 1951, p. 64).

This experiment has been vigorously criticized by Hochberg and Hochberg (1952) who have argued that Ittelson and others have failed to distinguish between familiar size, on the one hand, and the *relative* size of the stimuli on the other (i.e., change or difference in size of objects of similar shapes). For this reason, Hochberg and Hochberg (1952) designed an experiment in which familiar size and relative size were separated. Two figures were drawn on a two-dimensional, reversible screen drawing. One panel contained a drawing of a man, and on the other panel a boy of the same size and approximate contour was represented. The question is whether the panel with the boy appears to be nearer more often than the panel containing the man. This is to be expected if familiar size is determining apparent localization. The results showed that familiar size was ineffective in this situation.

In a second experiment the effectiveness of *relative* size was tested. The same procedure was followed with one difference. Whereas the first experiment held relative size constant while familiar size was varied, the second experiment held familiar size constant while varying relative size. Both panels contained drawings of the same boy, but one was a reduced version of the other. Here, relative size would lead to localizing the panel containing the larger boy nearer than the other panel. The results were in agreement with this expectation. These findings led the authors to suggest that there may be a stimulus bound correlation between retinal size and perceived distance which would make the introduction of unconscious assumptions (about known size) unnecessary.

Further experimental evidence in support of this emphasis on relative size is presented by Hochberg and McAlister (1955). Four cards, each bearing one small figure and one large figure were presented singly. Card 1 bore a large circle and a small circle; Card 2, a large square and a small square; Card 3, a large circle and a small square; and Card 4, a large square and a small circle. In terms of relative size, it would be expected that Cards 1 and 2 should yield more three-dimensional responses than Cards 3 or 4. This was the case.

In a second experiment the authors inquired whether the direction of the three-dimensional responses is in accordance with what would be predicted in terms of relative size.

> In terms of the cue of relative size the larger figure should appear nearer than the small one in Cards 1 and 2. They did. If this were due to the operation of familiar size, we would expect similar results to hold with respect to Cards 3 and 4 (p. 296).

This did not happen.

Ittelson (1953) has replied to the above criticisms by citing several instances in which relative size is not involved. These are cases when only a *single* object is present in the field. Ittelson argues that if a single, familiar object viewed monocularly in a dark room is replaced by another of the same physical size, but of different assumed size, the apparent distance of the second will be different from the first. The clearest demonstrations of this effect have been Ames' "watch-card-magazine" experiment (1946–47) and Hastorf's similar investigations (1950). We will describe Hastorf's study later in this section when we consider Corollary 2.

In addition Ittelson (1953) maintains that if a single, familiar object is viewed monocularly in a dark room, it is perceived immediately and unequivocally at some definite distance which can be correctly predicted on the basis of the familiar size of the object. Finally, the claim is made that the size-distance perceptions related to a given stimulus can be changed by immediately prior experiences which change the size which is attributed to the stimulus. As an illustration Ittelson cites the experiments which demonstrate the influence of size assumptions on perceived radial motion (see Kilpatrick & Ittelson, 1951).

The latter two assertions are incompatible with an explanation based on the relative size cue. However, subsequent investigations have failed to confirm their validity, and have provided further support for the relative size thesis (also see Hochberg & Hochberg's—1953—rejoinder to Ittelson). The experiments reported by Gogel, Hartman, and Harker (1957) show that the retinal size of a familiar object is totally inadequate as a cue for the *absolute* apparent distance of that object. The investigations reported by Epstein (in press) confirm the findings of Gogel et al. and also demonstrate that experiences which modify *O*s assumptions concerning object size do not modify his perceptual experience. The problem for Gogel et al. (1957) was to "investigate whether the retinal subtense of a familiar object can act as a determiner of the apparent *absolute* distance of that object from the observer" (p. 1). This study employed a nonvisual method of measuring perceived distance of the object. *O* was asked to throw a dart to the perceived distance without seeing the results of the throw. Since successive throws might involve relative distance judgment, only the response to the object which was *first* perceived was considered in measuring the perceived absolute distance of that object. The stimulus object was a normal or double sized playing card, located at a distance of 10 or 20 feet in a reduced cue situation.

The distance responses for the stimuli initially presented did not confirm the expectations which follow from the Known Size-Apparent Distance Hypothesis. Not only did the results fail to agree with any precise predictions of apparent localization, e.g., the double sized card at a physical distance of 20 feet should be localized at 10 feet, but the less stringent prediction, e.g., the double sized card should appear to be nearer than the normal card, was also not confirmed. Under these conditions perceived distance was totally unrelated to retinal size.

When a similar analysis was performed for all of the four reduced cue situations collectively (i.e., the *same* *O*s in all four situations), partial support was obtained for the Known Size-Apparent Distance Hypothesis in its less precise formulation. The implication of this finding is clear. The secondary analysis shows only that *relative* distance perception, as some function of *relative* retinal subtense, can occur for successively presented stimuli.

The first of three experiments reported by Epstein (in press) was essentially a replication of Ittelson's (1951) experiment with two major modifications: (*a*) prior to the judgmental task *O*s in the Experimental Group participated in a card game which was designed to modify their assumption concerning the normal size of cards, and the constancy of the physical size of cards, (*b*) at the conclusion of the distance settings all *O*s were required to judge the apparent size of the stimuli.

The results of this experiment did not support the known size hypothesis. Despite the modifying treatment experienced by the Experimental Group there was no difference between the distance judgments of the Experimental Group and a Control Group which did not have prior training. In addition, none of the distance judgments met the precise quantitative requirements of the known size thesis, e.g., while the quarter sized card appeared to be more distantly located than the normal card, it was *not* set at four times the distance of the normal card. Finally, the stimuli of different physical size were also judged to be of different size.

In Experiment II it was demonstrated that similar apparent distance effects would obtain when only relative retinal size is operative (known size and assumed constancy of physical size absent). Finally, in Experiment III it was shown that in the absence of the relative size cue no systematic size-distance effects are obtained. The results of Experiments II and III bolster the position adopted by Hochberg and Gogel.

In this connection the results reported by Gogel and Harker (1955) may also be cited. Gogel and Harker obtained judgments of apparent distance for two playing cards of different sizes under reduced cue and near complete cue conditions. They found that the relative apparent depth of the two cards was a function of the lateral separation between the two cards. They concluded that "the effectiveness of size cues to relative depth increased as the lateral separation of the differently sized cards was increased" (p. 315). There is no reason to expect such results if the original depth effects were based on the operation of an assumed size factor.

This review leads to the conclusion that despite its reasonableness Corollary 1 of the Known Size-Apparent Distance Hypothesis is unnecessary. Many of the experimental effects which are most frequently cited as evidence for its validity are more simply attributed to other factors, e.g., relative size. In those cases in which these factors are eliminated the "Known Size Effect" is also eliminated. The question remains whether all reported effects of known size on apparent localization can be explained in this way. This brings us to Corollary 2 of the Known Size-Apparent Distance Hypothesis.

Corollary 2

The second corollary requires that a *single* object whose physical size remains unaltered will undergo changes in apparent spatial localization with changes in the physical size which *O* attributes to the object. Thus, if the same object is assumed by *O* to have a small size at one time, and a large assumed size at a later time, it will be perceived to be more distant at this later time although the physical distance of the object is the same at both times. It is obvious that effects of this nature cannot be accounted for by processes which depend on the opportunity for comparisons of successively presented stimuli which differ along a physical dimension.

There are very few experimental studies which demonstrate that such an effect does indeed obtain. In Hastorf's (1950) investigations a rectangular or circular area of light was given a "large assumed size meaning" or a "small assumed size meaning." That is, the rectangle was called either an envelope or a calling card, and the circle was called either a billiard ball or a ping-pong ball. The size at which the stimulus was set, in order to appear at a specific distance, varied when the assumed size attributed to the stimulus was varied by the size suggestion, i.e., by naming the stimulus.

In a study of the effects of past experience on apparent size, Smith (1952) reported findings which may be interpreted in the same way. In the first stage of the experiment *O* judged the apparent distance of several simple geometrical forms, e.g., circles and squares. Then, over a period of 2.5 weeks *O*s participated in a series of tasks requiring the manipulation and discrimination of geometrical forms of the same shape but larger in size. In this way *E* hoped to alter the attributed size of the original forms. Then the *O*s were retested, i.e., *O*s repeated the judgments which were made prior to training. The distance judgments were observed to change in the direction demanded by the modification in attributed size.

Finally some incidental findings of Ittelson (1951) may be mentioned. In one variation of the experiment described earlier *O* judged the apparent distance of a half sized playing card and a matchbox of identical size when both were located at the same objective distance of 7.5 feet. The playing card was localized at a distance of 14.99 feet while the matchbox was judged to be at a distance of 8.96 feet. Apparent distance was influenced by *O*s assumptions concerning the physical size of the stimulus objects.

Corollary 2 has received support from the investigations described above. Still, there is clearly a need for further experimentation. In particular it would be useful to have the results of experiments which meet the following three requirements:

1. A measure of *O*'s *immediate* perceptual impression should be obtained. In most cases *O* has been allowed an extended period of time in which to make an adjustment which he is "satisfied with." Under such conditions many judgmental and attitudinal factors may enter into the adjustment process, and contaminate or at least alter the identity of the effect.

2. Different *O*s should be used for the various attributed size conditions. It is possible that the same *O* performing under the various conditions may be making memorial comparisons between the first attributed size-apparent distance judgment and the requirements of the current situation. This possibility is minimized if an extended temporal interval intervenes between the required judgments. Nonetheless, even though 6 days intervened between successive critical judgments in Hastorf's experiments, Hastorf (1950) reports that "some subjects did appreciate the fact that it was the same stimulus objects being given two different names" (p. 208).

3. In addition to these two requirements it might be helpful to obtain a measure of apparent size independently of *O*'s distance judgments. The results of earlier experiments suggest that such information may be instructive.

The Relationship between the Size of the Afterimage and Distance

A special case of invariance is Emmert's Law. The law states that the size of a projected afterimage (AI) is directly proportional to the distance from the eye to the projection surface. This statement follows from simple geometric considerations if we keep in mind that for the case of AIs the subtended visual angle remains constant regardless of variations in projection distance. The apparent simplicity disappeared following Boring's (1940) well-known attempt to demonstrate that Emmert's Law implies its converse, size constancy. Boring's thesis has been expressed succintly by Edwards (1950):

> What Boring was saying was that apparent size must increase with constant retinal size and increasing distance, if it is also true that apparent size remains constant with shrinking retinal size and increasing distance (p. 611).

We will not review the logic of Boring's formulations. It will suffice to point out that these formulations hinge on Boring's substitution of apparent size for physical size in the optical geometry of Emmert's Law. This substitution has been strongly criticized by Young (1950). Nevertheless, Boring's thesis has stimulated the major portion of writings concerned with Emmert's Law in the last 10 years. This work has followed two main themes.

The Historical Issue

Young (1950, 1951) has contended that Emmert intended to deal only with nonpsychological, Euclidian optical relationships. The contention is that Emmert's original reference (1881) was to the physical size of the

AI as determined by direct physical measurement of the occluded area on the projection surface. Young also maintains that a fundamental difference exists between real objects and AIs, and that it is inappropriate to speak of the apparent size of the latter.

The opposing view holds that Emmert was either concerned directly with apparent size and had, himself, implicitly made the substitution of *s* for *p* for the special case of AIs (Edwards, 1950), or that he did not distinguish the two different meanings of size perception (Boring & Edwards, 1951). The determination of apparent size requires a comparative technique. This method usually takes the form of judging the size of the critical object on the basis of an adjustable comparison stimulus or a series of different sized stimuli. These, generally, are separated both in the lateral and frontal plane from the critical object. This method has found wide application in research on size constancy where apparent size is the crucial dimension.

Despite a careful reading of Emmert's original article (1881) there is little that we can contribute toward a resolution of this historical issue.[4] The one experiment which Emmert described in detail did utilize comparative stimuli, but both were attached directly to the projection surface. We are inclined to agree with Boring and Edwards (1951) that Emmert, in his own research, was not making a clear distinction between physical and apparent size.

The Theoretical Issue

The second aspect of the controversy is of greater significance. If Emmert's Law and size constancy are derivable from the same processes, then those conditions which determine the perceived size of real objects should affect the size of the AI also. If communality of process is not the case then the size of the AI should be unaffected by the same variables which affect the perceived size of real objects (or at least the effects should not be identical).

Edwards (1950) suggested that an experimental decision on this matter depends in part on the selection of an appropriate method of measurement. *E* can adopt either of two methods: (*a*) indirect measurement by employing a comparison stimulus or (*b*) direct measurement on the plane of projection. Edwards predicted that under reduced cue conditions Emmert's Law would fail when measured by Method *a* (i.e., the size of the AI would remain constant with increasing distance) but would hold when measured by Method *b*. Much of Edwards' position had been stated earlier by Helson (1936). In this paper Helson interpreted his results as showing that:

> when cues to distance and surroundings are eliminated the apparent size remains practically constant while the measured size of the projected image tends to obey Emmert's Law (p. 638).

Edwards (1953) tested one aspect of this prediction, viz., that the apparent size of the AI when measured by the comparison method would not conform to Emmert's Law under reduced cue conditions. *Os* projected AIs monocularly on to a dimly illuminated screen while looking through a reduction tube. The distance of the projection screen varied in five steps from 42 to 90 inches. A 2-inch luminous square in the same reduced field was adjusted until it appeared equal in size to the AI. No significant differences between the various dis-

[4] We are indebted to Martin Scheerer of the Department of Psychology of the University of Kansas for his expert translation of Emmert's article.

tances were obtained. Edwards concluded that Emmert's Law (i.e., "Emmert's Law of Apparent Size") had failed under reduction conditions. However, as Edwards himself admits, it is somewhat tenuous to uphold a prediction on the basis of confirmation of the null hypothesis.

Hastorf and Kennedy (1957) also contend that the controversy concerning the relationship of Emmert's Law to size constancy is primarily a matter of the type of measurement used. Under reduction and nonreduction conditions *O*s judged the size the real objects and AIs at various distances by the comparison method and the direct method (bracketing spotlights). The results for the comparison method confirmed Edwards' position, i.e., in the reduced cue situation, size constancy was greatly decreased and Emmert's Law did not obtain. With direct measurement there was no significant difference in the size of the AI between the reduced and full cue situations. This outcome supports Young's position. Thus, both sides of the controversy received support as did the authors' contention that the controversy hinges on different measurment techniques. However, Hastorf and Kennedy also reported that the use of bracketing spotlights in a dark room might provide a distance cue. If this is true, then it must be concluded that the direct measurement of the physical size of the AI under authentic reduction conditions remains to be accomplished.

Crookes (1959) takes a somewhat different approach to the problem of measurement. Crookes agrees with Young (1950, 1951) that Emmert's Law concerns "real," not apparent size. Further, he proposes that if Boring (1940) is right, Emmert's Law and size constancy should hold equally well when apparent size matches are obtained under the same conditions. Using the comparison method under "analytical" instructions, i.e., stressing retinal size, *O*s matched AIs and real objects. Crookes found that *O* made significantly better matches (i.e., showed significantly more constancy) in the case of the real objects. Crookes concludes that the subsumption of Emmert's Law and size constancy under a common heading is not justified. However, the objection could be raised that the analytical attitude induced by the instructions does not suit the purposes of research on constancy phenomena. Also, there is some question whether the greater constancy in the case of the real objects might not be due to the relatively greater ease of viewing real objects.

These studies concerned with the relationship between Emmert's Law and size constancy are not unanimous in their conclusions. Nevertheless, it is generally conceded that the method of measuring the AI may be critical. Thus, we might expect two or more forms of Emmert's Law to emerge, each embodying its own mode of measurement and each bearing a different relationship to other size-distance phenomena.

New approaches to measurement should be tried in this context, especially those promising some increase in precision. For example, Onizawa (1954) has developed a method whereby a screen bearing a comparison stimulus moves away from *O*, while a projection screen bearing an AI moves toward *O*. When *O* perceives equality between the AI and the comparison stimulus, he stops this movement. Ratios based on the respective distances of the two screens from *O* are compared with like ratios predicted from Emmert's Law. Onizawa presents data which indicate that his technique incurs less variability than the method of directly measuring the AI on the projection surface.

However, before the role of different measures can be clearly evaluated it will be necessary to test them together under identical conditions (e.g., reduction conditions). This requires that a given measure must not, itself, disqualify such conditions. Hastorf and Kennedy's (1957) observation (i.e., spotlights provide distance cues under reduced conditions) illustrates this problem.

Another matter deserving comment is related to the hybrid nature of Boring's formulation. While Boring has substituted apparent size for real size he has not seen fit to substitute apparent distance for physical distance. A careful reading of Boring's discussion (1942, p. 292) reveals a confusion of physical distance with apparent distance. The two terms are used interchangeably, seemingly without regard for any differences which may exist. It would be interesting to obtain pairings of the apparent size of the AI with the apparent distance of the projection surface. Such relationships if found to conform to Emmert's Law could hardly be explained in terms of the requirements of Euclidian geometry which applies only to physical distances and extents.

In this regard an additional complicating factor has been described by Ohwaki (1955). While expected values of Emmert's Law have been based on retinal size arising from the physical size and distance of the fixation object, Ohwaki (1955) found that perceived, not physical, distance was crucial in determining retinal size. Perceived distance was effective with either ordinary distance cues or past experience available. The interpretation was offered that it is perceived distance which underlies accommodation. Accommodation in turn regulates the size of the retinal image.

Finally, the problem of the physical as opposed to apparent size of the fixation object should be mentioned. Although this problem has received recent treatment in studies of figural aftereffects, its relevance with respect to Emmert's Law has not been explored.

It seems obvious that a refined statement of Emmert's Law must await intensive treatment of the variables discussed above (i.e., apparent distance of the projection surface, apparent size and distance of the fixation figure).

Other Determinants of the Size of the Afterimage

In a series of experiments, Young investigated the effect of a number of additional variables on the size of projected AIs using spotlights to outline the AI on the projection plane. In one study Young (1952a) varied the exposure time of the stimulus object in seven steps ranging from 0.01 to 40.0 seconds. No significant variations in the size of the AI were found with variations in stimulation time. Young (1952b) also investigated several features of the projection ground. In one experiment the illumination on the projection ground was varied through five log steps. No variation in the size of the AI was found. Another experiment (1952b) utilized pictures containing strong linear perspective. AIs were projected to specified points on these pictures and compared with AIs projected to similar points on a blank screen. The surfaces with linear perspective were found to influence AI size. It is tempting to account for these results by referring to presumed changes in apparent distance resulting from the differences in geometric perspective. Unfortunately this interpretation is complicated by the finding that there was little agreement between the *Os* in degree or direction of the size effect. However, an earlier study by Frank reported by Koffka (1935, p. 212) lends credence to an apparent distance interpretation. Frank used a perspective drawing of a deep tunnel. AIs projected to a phenomenally remote part of this tunnel were considerably larger than those projected to a near part. A similar effect is observed in the "Afterimage Demonstration" (Ittelson, 1952, pp. 32–33). Appropriate adjustments of the interposition indications using the overlay demonstration apparatus (Ittelson, 1952, p. 13) produce changes in the apparent distance of the projection surface and proportional changes in the apparent size of the AI.

The final study in this series (Young, 1952c) concerned the effect of large distances. In daylight AIs were projected in an open field to distances ranging from 25 to 1,250 meters. In each case obtained values were less than those expected on the basis of Emmert's Law. The hypothesis was advanced that with a brighter fixation stimulus (a square with a luminance of approximately 1,700 millilamberts), the retinal image is smaller, and consequently, the AI is smaller.

An interesting sidelight to the type of research on Emmert's Law considered so far is Oswald's (1957) study of the peripheral and central origins of AIs. Oswald uses these terms to contrast AIs in which the stimulation is confined to the retina with those involving the higher "representative" or brain centers. He cites a number of investigations, including his own in which AIs were obtained peripherally by presenting a light to an eye temporarily blinded by local pressure to the eyeball. Oswald also reviews a number of positive and negative reports of "central" AIs following imagined (visualized) objects or objects experienced in dreams. In his main experiment *Os* "imagined" crosses or squares and then projected AIs to a screen at various distances. Most *Os* were able to achieve AIs to imagined stimuli. However, very few AIs conformed to Emmert's Law. In this regard Oswald cites several earlier reports that eidetic *Os* deviate markedly from Emmert's Law when real stimuli are employed.

With further reference to individual differences, Brengelman (1956) found deviations from Emmert's Law to be larger in his neurotic group than with normals and psychotics.

Both large individual differences, such as those reported by Oswald, as well as smaller but consistent ones are inexplicable from the standpoint of a purely physical law. As an example of the latter kind, Young (1948) reported that all of his *Os* ($N=5$) yielded values falling consistently short of Emmert's Law values by a small margin. One would expect that variations due to inaccuracies of measurement alone would be randomly distributed.

Concluding Discussion

It seems to us that at least one compelling conclusion emerges from the survey we have just completed: the size-distance relationship expressed in the several formulations of the invariance hypothesis should not be assigned a unique or primary status in explanations of space perception. We have seen that this is only one of the several possible and actual relationships which are obtained. This need not cause any great consternation to those who recall the origin of the hypothesis in Euclidean geometrical principles. Although the distinction is sometimes overlooked it should be clear that the invariance hypothesis is a psychological proposition, and not a geometrical proposition. By no stretch of the imagination can Euclid's principles be applied *directly* to space perception. Of course, the analogy is plain and very tempting, and a successful translation would have been a happy logical circumstance. Nonetheless, failure to accomplish this translation should not cause surprise.

This brings us to a second remark. A great deal of logical and experimental analysis has been aimed at clarifying the term "size." We now distinguish not only real physical size, apparent size, and retinal size, but also assumed size, apparent angular size, etc. Usually the investigator makes explicit which aspect of size perception he is dealing with. However, with regard to distance, there is often a confusion of physical distance and apparent distance. We have seen that there is no unequivocal 1:1 relationship between physical distance and apparent distance. Therefore, it is not clear how experimental investigations of the size-distance relationship are to be interpreted when apparent distance judgments are not obtained. It seems to us that all studies of size and distance should obtain paired size-distance judgments.

This brings us to the methodological point which we mentioned earlier. Almost all of the experiments which have obtained paired size-distance judgments (including Epstein, in press) have done so in a successive judgment situation. We have already indicated the reasons for our dissatisfaction with this procedure. Here we wish only to reiterate the desirability for future investigation which employs a simultaneous judgment technique.

Finally, we wish to endorse a comment made earlier by Kilpatrick and Ittelson (1953) concerning individual differences. In order to assess the generality of the various size-distance hypotheses we need to look more carefully at the results of the performances of individual *O*s. In repeating some of the published research the first author has often been struck by the degree of interobserver and intraobserver variability. Results confirming various aspects of the invariance hypothesis do not allow *E* to say much about the individual *O*. In view of the "lawfulness" which is usually ascribed to the invariance hypotheses this extreme variability cannot be overlooked.

REFERENCES

Adler, F. H. *Gifford's textbook of opthalmology.* (7th ed.) Philadelphia: Saunders, 1959.

Allen, M. J. An investigation of the time characteristics of accommodation and convergence of the eyes. *Amer. J. Optom.*, 1953, **30**, 393–402.

Ames, A., Jr. *Nature and origin of perception: Preliminary laboratory manual for use with demonstrations disclosing phenomena which increase our understanding of the nature of perception.* Hanover: Inst. Ass. Res., 1946–47.

Bartley, S. H. *Principles of perception.* New York: Harper, 1958.

Bedrossian, E. H. *The eye: A clinical and basic science book.* Springfield: Charles C Thomas, 1958.

Bleything, W. B. Factors influencing stereoscopic localization. *Amer. J. Optom.*, 1957, **34**, 416–429.

Boring, E. G. Size-constancy and Emmert's law. *Amer. J. Psychol.*, 1940, **53**, 293–295.

Boring, E. G. *Sensation and perception in the history of experimental psychology.* New York: Appleton-Century, 1942.

Boring, E. G., & Edwards, W. What is Emmert's law. *Amer. J. Psychol.*, 1951, **64**, 416.

Brengelmann, J. C. Duration, periodicity, distortion and size of the negative visual afterimage in neurosis and psychosis. *Psychol. Beit.*, 1956, **2**, 569–585.

Brunswik, E. *Perception and representative* *design of psychological experiments.* Berkeley: Univer. California Press, 1956.

CARLSON, V. R. Apparent size, apparent distance, and real confusion. Paper read at American Psychological Association, Chicago, September 1960. (Complete text obtainable from Convention Reports Duplicating Service, Cleveland.) (a)

CARLSON, V. R. Overestimation in size-constancy judgments. *Amer. J. Psychol.*, 1960, **73**, 199–213. (b)

CHALMERS, E. L. Monocular and binocular cues in the perception of size and distance. *Amer. J. Psychol.*, 1952, **65**, 415–423.

CHALMERS, E. L. The role of brightness in primary size-distance perception. *Amer. J. Psychol.*, 1953, **66**, 584–592.

COMALLI, P. E., JR. The effect of time on distance-perception. *Clark U. Bull.*, 1951, **23**(203), 139–140. (Abstract)

COULES, J. Effect of photometric brightness on judgments of distance. *J. exp. Psychol.*, 1955, **50**, 19–25.

CROOKES, T. G. The apparent size of after-images. *Amer. J. Psychol.*, 1959, **72**, 547–553.

DEMBER, W. N. *Psychology of perception.* New York: Holt, 1960.

EDWARDS, W. Emmert's law and Euclid's optics. *Amer. J. Psychol.*, 1950, **63**, 607–612.

EDWARDS, W. Apparent size of after-images under conditions of reduction. *Amer. J. Psychol.*, 1953, **66**, 449–455.

EMMERT, E. Grössenverhältnisse der Nachbilder. *Klin. Mbl. Augenheilk.*, 1881, **19**, 443–450.

EPSTEIN, W. The known size-apparent distance hypothesis. *Amer. J. Psychol.*, in press.

GELDREICH, E. W. A lecture-room demonstration of the visual tau effect. *Amer. J. Psychol.*, 1934, **46**, 483–485.

GIBSON, E. J., & SMITH, J. The effect of training in distance estimation on the judgment of size-at-a-distance. *USAF Hum. Resour. Res. Cent. res. Bull.*, 1952, No. 52–39.

GIBSON, J. J. (Ed.) Motion picture testing and research. *AAF Aviat. Psychol. res. Rep.*, 1947, No. 7.

GIBSON, J. J. *The perception of the visual world.* Boston: Houghton Mifflin, 1950.

GILINSKY, A. S. Perceived size and distance in visual space. *Psychol. Rev.*, 1951, **58**, 460–482.

GILINSKY, A. S. The effect of attitude upon the perception of size. *Amer. J. Psychol.*, 1955, **68**, 173–192. (a)

GILINSKY, A. S. The relation of perceived size to perceived distance: An analysis of Gruber's data. *Amer. J. Psychol.*, 1955, **68**, 476–480. (b)

GOGEL, W. C. Relative visual directions as a factor in depth perceptions in complex situations. *USA Med. Res. Lab. Rep.*, 1954, No. 148.

GOGEL, W. C. Relative visual direction as a factor in relative distance perceptions. *Psychol. Monogr.*, 1956, **70**(11, Whole No. 418). (a)

GOGEL, W. C. The tendency to see objects as equidistant and its inverse relation to lateral separation. *Psychol. Monogr.*, 1956, **70**(4, Whole No. 411). (b)

GOGEL, W. C., & HARKER, G. S. The effectiveness of size cues to relative distance as a function of lateral visual separation. *J. exp. Psychol.*, 1955, **50**, 309–315.

GOGEL, W. C., Hartman, B. O., & HARKER, G. S. The retinal size of a familiar object as a determiner of apparent distance. *Psychol. Monogr.*, 1957, **71**(13, Whole No. 442).

GRUBER, H. E. The relation of perceived size to perceived distance. *Amer. J. Psychol.*, 1954, **67**, 411–426.

GRUBER, H. E. The size-distance paradox: A reply to Gilinsky. *Amer. J. Psychol.*, 1956, **69**, 469–476.

GULICK, W. L., & STAKE, R. E. The effect of time on size-constancy. *Amer. J. Psychol.*, 1957, **70**, 267–279.

HASTORF, A. H. The influence of suggestion on the relation between stimulus size and perceived distance. *J. Psychol.*, 1950, **29**, 195–217.

HASTORF, A. H., & KENNEDY, J. L. Emmert's law and size-constancy. *Amer. J. Psychol.*, 1957, **70**, 114–116.

HASTORF, A. H., & WAY, K. S. Apparent size with and without distance cues. *J. gen. Psychol.*, 1952, **47**, 181–188.

HEINEMANN, E. G., TULVING, E., & NACHMIAS, J. The effect of oculomotor adjustments on apparent size. *Amer. J. Psychol.*, 1959, **72**, 32–45.

HELSON, H. Size constancy of projected after images. *Amer. J. Psychol.*, 1936, **48**, 638–42.

HERMANS, T. G. The relationship of convergence and elevation changes to judgments of size. *J. exp. Psychol.*, 1954, **48**, 204–208.

HOCHBERG, C. B., & HOCHBERG, J. E. Familiar size and the perception of depth. *J. Psychol.*, 1952, **34**, 107–114.

HOCHBERG, C. B., & HOCHBERG, J. E. Familiar size and subception in perceived depth. *J. Psychol.*, 1953, **36**, 341–345.

HOCHBERG, J. E., & MCALISTER, E. Relative size vs. familiar size in the perception of represented depth. *Amer. J. Psychol.*, 1955, **68**, 294–296.

HOLWAY, A. H., & BORING, E. G. Determinants of apparent visual size with distance variant. *Amer. J. Psychol.*, 1941, **54**, 21–37.

HOWARTH, E. The role of depth of focus in depth perception. *Brit. J. Psychol.*, 1951, **42**, 11–20.

ITTELSON, W. H. Size as a cue to distance. *Amer. J. Psychol.*, 1951, **64**, 188–202.

ITTELSON, W. H. *The Ames demonstrations in perception.* Princeton: Princeton Univer. Press, 1952.

ITTELSON, W. H. Familiar size and the perception of depth. *J. Psychol.*, 1953, **35**, 235–240.

JENKIN, N. Effects of varied distance on short-range size judgments. *J. exp. Psychol.*, 1957, **54**, 327–331.

JENKIN, N. A relationship between increments of distance and estimates of objective size. *Amer. J. Psychol.*, 1959, **72**, 345–364.

JENKIN, N., & HYMAN, R. Attitude and distance-estimation as variables in size-matching. *Amer. J. Psychol.*, 1959, **72**, 68–77.

JUDD, C. M. An optical illusion. *Psychol. Rev.*, 1898, **5**, 286–294.

KAUFMAN, L., & ROCK, I. The moon illusion: The problem reopened. Paper delivered at Eastern Psychological Association, Philadelphia, April 1960.

KILPATRICK, F. P., & ITTELSON, W. H. Three demonstrations involving the visual perception of movement. *J. exp. Psychol.*, 1951, **42**, 394–402.

KILPATRICK, F. P., & ITTELSON, W. H. The size-distance invariance hypothesis. *Psychol. Rev.*, 1953, **60**, 223–231.

KOFFKA, K. *Principles of gestalt psychology.* New York: Harcourt, Brace, 1935.

LEIBOWITZ, H., CHINETTI, P., & SIDOWSKI, J. Exposure duration as a variable in perceptual constancy. *Science*, 1956, **123**, 668–669.

LICHTEN, W., & LURIE, S. A new technique for the study of perceived size. *Amer. J. Psychol.*, 1950, **63**, 281–282.

OHWAKI, S. On the factors determining accommodation: Research on size constancy phenomenon. *Tohuku psychol. Folia*, 1955, **14**, 147–158.

ONIZAWA, T. Research on the size of the projected after-image: I. On the method of measurement. *Tohuku psychol. Folia*, 1954, **14**, 75–78.

OSWALD, I. After images from retina and brain. *Quart. J. exp. Psychol.*, 1957, **9**, 88–100.

PASCAL, J. I. Effect of accommodation on the retinal image. *Brit. J. Ophthalmol.*, 1952, **36**, 676–678.

PURDY, J., & GIBSON, E. J. Distance judgment by the method of fractionation. *J. exp. Psychol.*, 1955, **50**, 374–380.

RENSHAW, S. Object perceived-size as a function of distance. *Optom. Wkly.*, 1953, **44**, 2037–2040.

ROELOFS, C. O., & ZEEMAN, W. P. C. Apparent size and apparent distance in binocular and monocular distance. *Ophthalmologica*, 1957, **133**, 188–204.

SINGER, J. L. Personal and environmental determinants of perception in a size constancy experiment. *J. exp. Psychol.*, 1952, **43**, 420–427.

SMITH, O. W. Distance constancy. *J. exp. Psychol.*, 1958, **55**, 388–389.

SMITH, W. M. Past experience and the perception of visual size. *Amer. J. Psychol.*, 1952, **65**, 389–403.

SMITH, W. M. A methodological study of size-distance perception. *J. Psychol.*, 1953, **35**, 143–153.

TADA, H. Overestimation of farther distance in depth perception. *Jap. J. Psychol.*, 1956, **27**, 204–208.

VERNON, M. D. *A further study of visual perception.* Cambridge: Cambridge Univer. Press, 1954.

WALLACH, H., & MCKENNA, V. V. On size-perception in the absence of cues for distance. *Amer. J. Psychol.*, 1960, **73**, 458–460.

WOHLWILL, J. F. Developmental studies of perception. *Psychol. Bull.*, 1960, **57**, 249–288.

WOODWORTH, R. S., & SCHLOSBERG, H. *Experimental psychology.* (Rev. ed.) New York: Holt, 1954.

YOUNG, F. A. The projection of after images and Emmert's law. *J. gen. Psychol.*, 1948, **39**, 161–166.

YOUNG, F. A. Boring's interpretation of Emmert's law. *Amer. J. Psychol.*, 1950, **63**, 277–280.

YOUNG, F. A. Concerning Emmert's law. *Amer. J. Psychol.*, 1951, **64**, 124–128.

YOUNG, F. A. Studies of the projected after images: I. Methodology and the influence of varying stimulation times. *J. gen. Psychol.*, 1952, **46**, 73–86. (a)

YOUNG, F. A. Studies of the projected after images: II. The projection ground and the projected image. *J. gen. Psychol.*, 1952, **47**, 195–205. (b)

YOUNG, F. A. Studies of the projected after images: III. The projection over large distances. *J. gen. Psychol.*, 1952, **47**, 207–212. (c)

ZEIGLER, P., & LEIBOWITZ, H. Apparent visual size as a function of distance for children and adults. *Amer. J. Psychol.*, 1957, **70**, 106–109.

(Received September 21, 1960)