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THE SIZE CUE TO VISUALLY PERCEIVED DISTANCE

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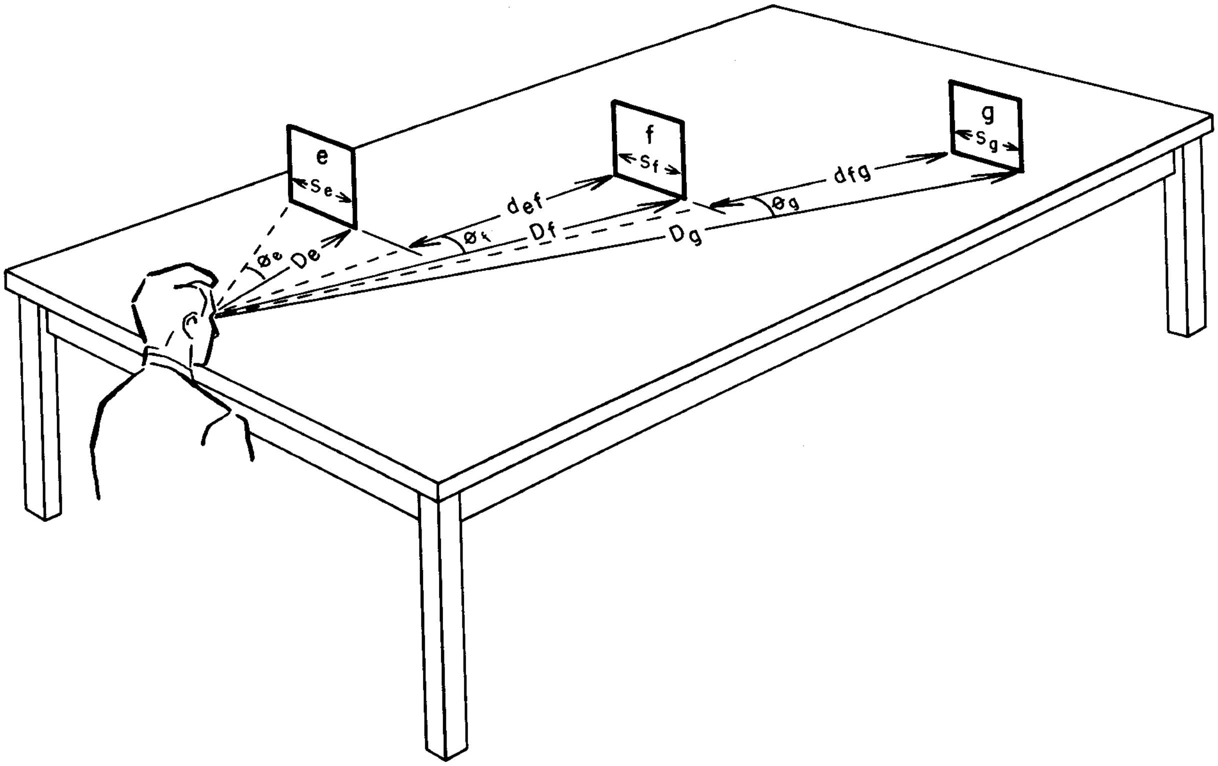

Figure 1. A schematic perspective drawing useful in considering terms involved in the operation of size as a cue to distance. This figure has appeared previously as Figure 1 in Gogel (1964b).

ence in the retinal sizes of the rectangles. Under these conditions, neither rectangle by itself would be perceived as having a unique size. However, the rectangles are assumed by *O* to be of the same size, and therefore, $S'_e = S'_f$. If D_f is greater than, equal to, or less than D_e, and $S_e = S_f$, it follows that θ_f is less than, equal to, or greater than θ_e, respectively. When $S'_e = S'_f$, and $\theta_e > \theta_f$, Rectangle *f* is perceived as more distant than Rectangle *e* (d'_{ef} is positive). When $S'_e = S'_f$ and $\theta_e < \theta_f$, Rectangle *f* is perceived as less distant than Rectangle *e* (for consistency, d'_{ef} should be considered as negative) and when $S'_e = S'_f$ and $\theta_e = \theta_f$, the two rectangles are perceived to be at the same distance (d'_{ef} is zero).

There is evidence that the simultaneous visual presentation of two similar but non-familiar objects such as Rectangles *e* and *f* in Figure 1, in the absence of other depth cues, will result in a perceived depth d'_{ef}. The term non-familiar is used here to indicate that there are no familiar characteristics associated with the objects which would specify a perceived size. For example, although rectangles are shapes which are frequently encountered, there is no unique size which would normally be associated with them. It is reported (Kilpatrick, 1961) that a simultaneously presented series of lines of different retinal sizes whose centers are all at the same height will appear at different distances. The same phenomenon has been quantitatively demonstrated, for example, for a series of trapezoids (Gogel, 1954), for a pair of squares (Epstein & Baratz, 1964, Experiment I) and for a pair of discs (Updegraff, 1930; Carr, 1935, pp. 262-263), etc., (cf., Ittelson, 1960, p. 70). Similarly, two balloons of different visual angle but of the same brightness will appear at different distances with the perceived depth between them changing with continuous variation in the size of one (Kilpatrick, 1961).

The relative size cue to relative depth will be effective when the objects (*e*, *f*, and *g* of Figure 1) are presented successively, as well as simultaneously to the same *O* (Carr, 1935, pp. 260-261; Gogel, Hartman, & Harker, 1957; Over, 1963). The variability in the resulting perceived depth (d'), however, might be expected to increase as the time interval between the presentation of the two objects increased. The perception of a change in depth as a function of a continuous change in visual angle has also been demonstrated for a single non-familiar or familiar object (Ittelson, 1951b; Smith, 1951; Smith, 1952b; Smith, 1955; cf., Ittelson, 1960, p. 71). The evidence is clear. Objects of the same shape with visual angles which differ either successively (as in the case of the same object of different retinal sizes presented at different times to the same *O*) or simultaneously (as in the case of presenting two similar objects of different retinal size at the same time) or continuously (as in the case of the object whose visual angle changes while *O* is observing it) will result in a perception of relative depth.

Relative values of S' as well as θ are necessary in order for the relative size cue to result in a perceived distance. There is evidence (Hochberg & McAlister, 1955) that two simultaneously presented rectangles or two simultaneously presented circles of different retinal sizes can produce an apparent depth but, that the simultaneous presentation of a rectangle and circle of different retinal sizes does not. Clearly, some perception (S'_e and S'_f) of the relative sizes of the objects (*e* and *f*) is necessary. Neither S'_e nor S'_f must necessarily be perceived as being a particular size but some perception of the relation between the sizes is necessary. Also, while a difference in shape between two objects tends to destroy the perception of relative depth, it is not necessary that the two objects be identical in all characteristics except that of retinal size. It has been found, for example, that a depth perception can occur as the result of the simultaneous presentation of two squares of identical shape but different color (Epstein & Baratz, 1964, Experiment I). It is also unnecessary to assume that S'_e must equal S'_f in order for the relative size cue to result in a perception of relative depth. This can be shown by the results from a portion of a study by Over (1963) in which the perceived sizes and perceived distances of successively presented, diamond-shaped squares of various retinal sizes were measured under visually reduced conditions. The present author concludes that the results from this study by Over indicate that perceived distance can vary between presentations as a function of the changes in retinal size (see the dashed line curve of Figure 6) even though the perceived sizes of the squares were not always equal in the different presentations.

In summary the experimental evidence is in agreement with the following description of the essential processes involved in the relative size cue to relative distance: (1) The relative size which is referred to is a relative retinal size[1] and is a difference (or equality) in retinal sizes occurring from the simultaneous or successive presentation of similar objects. If the retinal sizes are different, a perception of depth between the objects will occur with the object having the retinally smaller size appearing more distant. If the retinal sizes are the same, the objects will appear equidistant. (2) Relative retinal size, by itself, is not sufficient to produce a perception of relative depth. Some similarity of shape between the objects must be present, and (3) must result in some perception of the relative sizes of the objects, with the usual perception being that of size equality. It is clear that relative values of S' as well as relative values of θ are involved in the relative size cue to relative depth.

[1] The expression "relative size judgments" (Gogel, et al., 1957) or "relative size" (Baird, 1963) has sometimes been used to refer to the perception of the relative sizes of objects presented either simultaneously or successively, regardless of whether the perceived size occurred between similarly shaped objects or not. Instead, the expression "relative size cue" in this paper follows the meaning used by Hochberg and McAlister (1955), i.e., the relative size cue as used in this paper is the relative depth cue which occurs from observing two (or more) similarly or identically shaped objects of different retinal size.

The Familiar Size Cue to Relative Distance

Familiar size as a cue to relative distance can also be considered with the aid of Figure 1. Suppose that Objects *e* and *f* are presented simultaneously and are monocularly viewed with the remainder of the field-of-view totally dark. Suppose also that Objects *e* and *f* are familiar objects, for example, two playing cards. Since $\theta_e > \theta_f$, Object *e* will be perceived as less distant than Object *f* (Ittelson, 1951c; Gogel, 1956a; Gogel & Harker, 1955). In this example, however, it is not necessary to resort to familiar size to explain the resulting perceived depth. An explanation in terms of relative size would be equally plausible (Hochberg & Hochberg, 1952; Hochberg & Hochberg, 1953; Hochberg & McAlister, 1955). Suppose, however, that Object *f* appears to be a similarly shaped but physically smaller object than a playing card, for example, a matchbox, with Object *e* continuing to be seen as a playing card. In this latter example, Object *f* might appear to be *less distant* than Object *e* even though $\theta_e > \theta_f$. According to the usual explanation of the familiar size cue, each of the objects (the matchbox and the playing card) should appear at a distance position which a normal-sized object of that particular category would have to occupy to produce that particular retinal size (Ittelson, 1951c). In the latter example since the objects are of similar shape and $\theta_e > \theta_f$, Object *f* should appear behind Object *e* according to the relative size cue but in front of Object *e* (for some values of $\theta_e > \theta_f$) according to the familiar size cue. Thus, it has been argued (Ittelson, 1960, p. 71; Epstein & Baratz, 1964) that the relative size cue and the familiar size cue in such situations are in opposition to each other.

The question as to whether the cue of familiar size has been demonstrated to be distinct from the cue of relative size has been answered in the affirmative by Ittelson (1951c) and in the negative by Hochberg and Hochberg (1952; 1953) and by Hochberg and McAlister (1955). A recent experiment by Epstein and Baratz (1964, Experiment II) is pertinent to this issue. In the experiment by Epstein and Baratz, perceived depth was measured between objects representing a dime, a quarter, and a half dollar presented in pairs. Each coin subtended three possible retinal sizes such that the relative and familiar size cues could be placed in agreement or in opposition. The results of the study indicate that the perceived depth between the pairs of coins when the two cue systems were in opposition was always in agreement with the familiar, not the relative size cue. It seems reasonable to conclude that the familiar size cue to relative depth cannot be subsumed under the relative size cue to relative depth.

Specification of the Significant Variable in the Size Cue to Relative Distance

From the previous discussion, it follows that in the perception of relative depth which results from the cues of relative and familiar size, the important variables are the relative values of S' and θ. In both the relative and familiar size cue, θ is determined by the physical size and physical distance of the stimulus objects. In the relative size cue, relative values of S' are determined by the perception that the identically shaped objects are identical or similar in size. In the familiar size cue, values of S' are determined by the size associated with each of the familiar objects. A difference in apparent size by itself does not determine a perceived relative distance. For example, in the case of the relative size cue, two identically shaped objects of *different* retinal sizes appear to be at *different* distances because they appear to be the *same* size. Also, perceived depth from the size cue is not determined solely by the relative retinal sizes of the objects. For example, as shown by Epstein and Baratz (1964) two objects of the *same* retinal size will appear to be at different distances because they appear to be of *different* sizes. It follows from such considerations that S' and θ considered jointly determine the perceived relative depth resulting from the size cue for both relative and familiar size. The point-of-view of this paper is that the significant variable in the size cue to relative depth is the relative values of S'/θ for each of the objects being considered.

The term S'/θ is the perceived size per unit of retinal size of the particular frontoparallel object being considered. When $S'_f/\theta_f > S'_e/\theta_e$, Object f is perceived to be more distant than Object e. When $S'_f/\theta_f = S'_e/\theta_e$, Objects e and f are perceived to be equidistant and when $S'_f/\theta_f < S'_e/\theta_e$, Object f is perceived to be less distant than Object e. It is asserted that the perceived depth d'_{ef} is a function of the values of S'/θ for the two objects. To apply the concept of S'/θ to the relative size cue, consider a situation in which the similarity of shape of the two non-familiar objects results, for example, in the perception that $S'_e = S'_f$. Thus, that object in the pair of objects which has the smallest value of θ will have the largest value of S'/θ and will appear to be the more distant object. To apply the concept of S'/θ to the familiar size cue consider a situation in which, for example, two objects (e and f) are of the same shape and retinal size ($\theta_e = \theta_f$) and are perceived to be a matchbox and a playing card, respectively. Since experience indicates that a playing card is larger than a matchbox, $S'_f > S'_e$ and thus $S'_f/\theta_f > S'_e/\theta_e$. Therefore, the playing card (f) will be perceived to be more distant than the matchbox (e). Familiar size and similarity of shape are merely different methods of determining values of perceived size (S'). Other factors such as assumptions (Hastorf, 1950) and sometimes, but not always, special experience (Smith, 1952a; Epstein, 1961) are also determiners of perceived size. Therefore, the familiar size cue and the relative size cue are never in opposition. It is the inequality in the perceived sizes of the objects regardless of the manner in which this inequality is produced which together with the retinal sizes results in a perceived depth. The concept that the relative values of S'/θ for the several objects determine the resulting perceived depth between the objects subsumes both the relative and familiar size cues into one system.

When Object e is of different shape than Object f, the concept of the relative size cue does not apply. If the objects are also familiar objects, however, the concept of the familiar size cue does apply. It has been asserted that relative depth judgments using the familiar size cue can be made under such conditions (Ittelson, 1951c; Ittelson, 1953). This assertion would also be made from the viewpoint taken in the present paper that variations in S'/θ between objects is the significant variable in the perception of relative depth from size cues. Two objects which differ in S'/θ, in the absence of other distance indicators, will be perceived at different distances. But, the concept of S'/θ is not only applicable to situations in which the familiar objects are of the same or similar shape. The concept of S'/θ as the significant variable in the size cue to relative depth will apply to irregularly shaped objects such as trees and animals as well as to geometric figures such as playing cards or circles. The application of S'/θ to differently or irregularly shaped objects is illustrated in Figure 2. Figure 2 illustrates three apparent frontoparallel planes labeled e', f', and g' located at different physical distances from O. A man is pictured as located in Plane e', a horse and tree in Plane f', and a house in Plane g'. It will be assumed that no distance cue other than that of size is available to determine the apparent depth between these planes and objects. According to the concept that S'/θ is the significant variable in the size cue, the objects in the different apparent frontoparallel planes are in different apparent frontoparallel planes because they have different values of S'/θ. Also, the objects in the same apparent frontoparallel plane (and all portions of an object in the same apparent frontoparallel plane) are in the same apparent frontoparallel plane because they have the same value of S'/θ. For example, suppose that two marks made on the trunk of the tree in Plane f' are separated by one degree of visual angle and are perceived to be separated by one foot. In this case, the S'/θ value is one foot per degree. A separation of one-half degree of visual angle anywhere else on the tree, or on the horse, or anywhere in Plane f' should appear to be six inches in length, giving thereby the same value of S'/θ. It follows that a constant value of S'/θ applies to an entire apparent frontoparallel plane including all the objects and interspaces within this plane regardless of their irregularity. Figure 2 is drawn to represent a situation in which the S'/θ values associated with the several apparent frontoparallel planes is greatest for g' and least for e'. Hence, g' and e' appear respectively

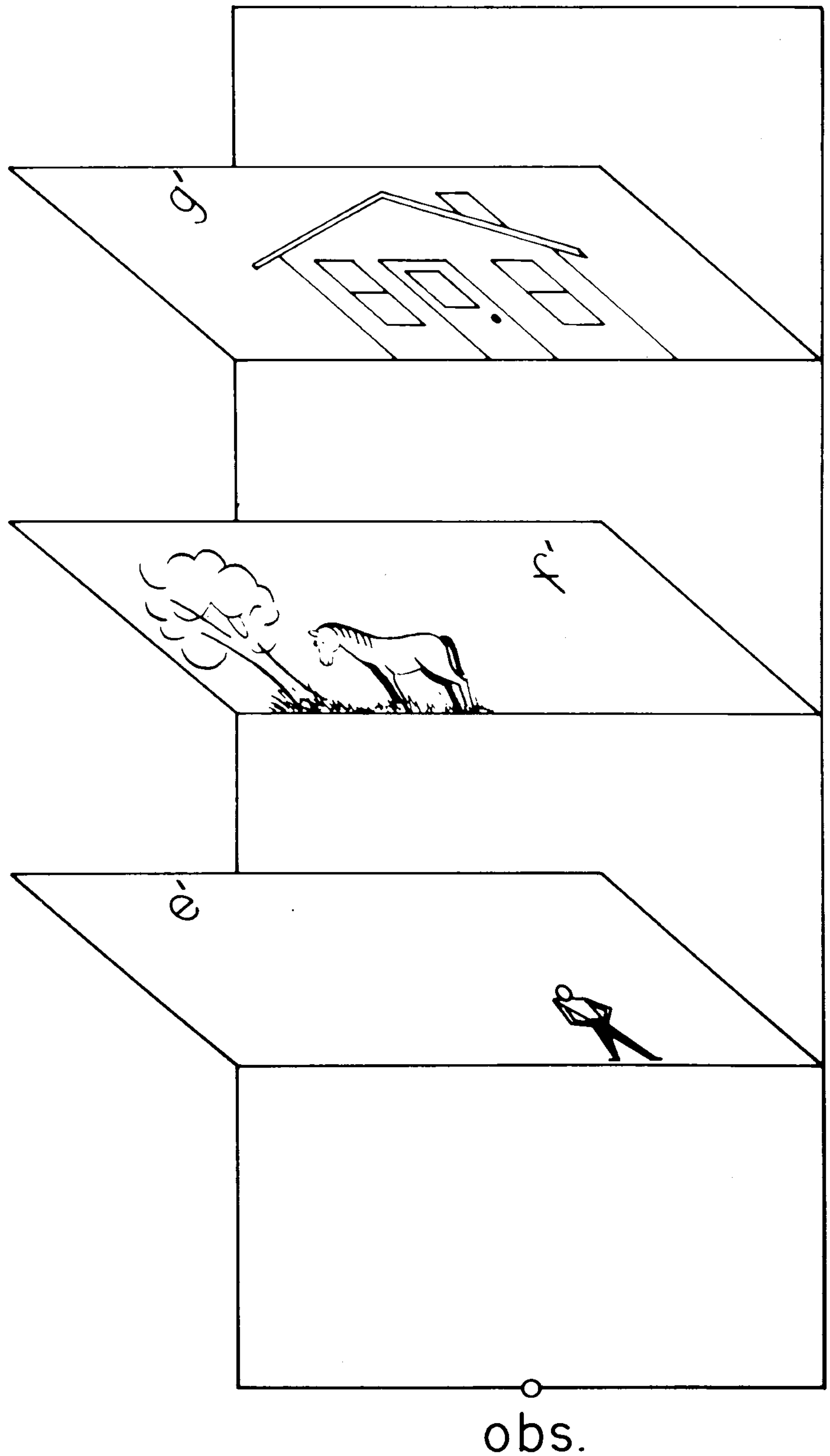

Figure 2. A schematic perspective drawing useful in considering the changes in perceived size per unit of retinal size for frontoparallel objects in different portions of the visual field.

behind and in front of f'. It is asserted that the different values of S'/θ between the different objects in the different planes will determine the perceived depth between these objects (or between the planes). In a situation in which the size cue to relative depth is the only distance cue present, it is hypothesized that all the perceived depths within this visual field are immediately specified by specifying the S'/θ values of the different objects.

The Size Cue to Absolute Distance

In the discussion involving Figure 1, the perceived distance D' of an object from O was called a perceived absolute distance to distinguish it from the perceived depth between objects d' (perceived relative distance). The size cue considered above is the size cue to perceived relative distance, not the size cue to perceived absolute distance. It is usually assumed (at least implicitly) that the reason why familiar size is a cue to perceived relative distance is because it is a cue to perceived absolute distance. It is supposed that experience will result in perceived absolute distances being associated with retinal sizes of a familiar object such that for any particular retinal size an appropriate absolute distance will be perceived (Ittelson, 1951c). From this point-of-view, a perceived relative distance is merely the difference between two perceptions of absolute distance. If this point-of-view is correct, the psychophysics of familiar size as a cue to relative distance is specified when the psychophysics of familiar size as a cue to absolute distance is known. Evidence relevant to this point-of-view will be examined in this portion of the paper.

A number of studies involving the so-called "thereness – thatness" type of apparatus have been interpreted as supporting the notion that the retinal size of a familiar object can determine a perceived absolute distance (Ittelson, 1951c; Hastorf, 1950; Ittelson & Ames, 1950; Epstein, 1963). In these studies the objects with the familiar (or assumed) size (the experimental objects) were presented in a visually reduced (experimental) field. The perceived distance of the experimental object was measured by comparing the apparent position of the experimental object with respect to that of a comparison object presented in a comparison field. The comparison object was either part of a visually well-structured field or was itself a familiar object. In either case, visual size comparisons could occur between the experimental object and objects in the comparison field. It has been asserted (Gogel, et al., 1957) that the measures obtained under these conditions have not been demonstrated to be measures of perceived absolute distance. The same assertion has been made recently (Adelson, 1963) in a study in which interactions between the experimental and comparison fields have been reported.

The kind of judgment which may occur when the "thereness – thatness" type of apparatus is used can be analyzed with the aid of Figure 2. Suppose that by means of appropriately placed mirrors, a playing card is made to appear in the visual field illustrated in Figure 2, with no cues present to localize the card in distance except its familiar size. The visual field illustrated in Figure 2 corresponds to the comparison field in the "thereness – thatness" apparatus while the playing card corresponds to the experimental object. The playing card will have a perceived size S' as determined by its familiar characteristics and also will have a retinal size θ. Thus, the playing card will have a particular value of S'/θ as will every object in the perceptually well-structured comparison field. If, as this paper asserts, S'/θ is the significant variable in the size cue to relative depth, the playing card will appear in that apparent frontoparallel plane in the comparison field which has the same value of S'/θ as does the playing card. All that is required of O for this perception to occur is a null comparison (a judgment of equality) of the S'/θ values of objects in the comparison field with respect to the S'/θ value of the playing card. Entirely incidental to this process is the question of how far the playing card appeared to be from O. No judgment of perceived absolute distance is required. The *physical* distance from O to the position of the plane (or to the position of objects in the plane) at which the card appears can be measured as is done with the "thereness – thatness" apparatus. But, if the point-of-view expressed in this paper is correct, this measure has nothing to do with *O*'s task and does not represent a perception of the absolute distance of the card. Similar comments apply when the method of measuring apparent distance involves adjusting the comparison object or the experimental object to apparent equidistance with each other. It is suggested that the results from the "thereness – thatness" apparatus demonstrate that experimental and comparison objects with the same S'/θ values appear equidistant but it is further suggested that the use of the "thereness – thatness" apparatus does not result in measures of perceived absolute distance. A similar type of objection has been stated previously (Gogel, et al., 1957) by noting that the measurement of the perceived absolute distance of a familiar object requires that a test situation be used in which only the familiar object is presented visually to *O*. A second requirement for the measurement of perceived absolute distance is not specific to the "thereness – thatness" type of apparatus. It is asserted that if different retinal sizes of the familiar object are used these must be presented to different *O*s. Comparisons can occur between successive presentations of different retinal sizes of the same or different familiar objects with the result that observer judgments which are actually judgments of relative distance may be interpreted by the experimenter (E) as being judgments of absolute distance.

From the point-of-view of the above criteria, there have been few adequate tests of whether familiar size is a cue to absolute distance. The study by Gogel, et al., (1957) was designed to meet the above requirements. Kinesthetic judgments and verbal reports were used to measure the perceived absolute distance to singly presented playing cards in visually reduced situations using different groups of *O*s for the first presentations of the different retinal sizes. Only the responses to the first presentations were considered to represent perceived absolute distances. Response changes as a function of successive presentations were considered to measure perceived relative distance. The results from this study indicate that the retinal size of a familiar object in isolation is not an effective cue to perceived absolute distance and also that the perception of relative depth which occurred between successive presentations of the cards occurred independently of any perception of absolute distance. A recent study by Epstein (1963), using figures of coins of three different denominations but constant retinal size as familiar objects and with a different group of *O*s viewing each coin, seems to support the point-of-view that familiar size is a cue to perceived absolute distance. However, since the judgments were made using a "thereness – thatness" type of apparatus, the experimental results do not necessarily measure perceived absolute distance but, instead, probably indicate the ability of *O*s to perceive that experimental and comparison objects which have the same value of S'/θ are equidistant.

A recent study by Baird (1963, Experiment II) meets the criteria discussed above. Three groups, with ten *O*s in each group, made verbal estimates of the distance of a luminous rectangular strip, with each group presented with a different retinal size. The *O*s were informed that the figure was the same size as a 12 inch ruler. The figure which was in a darkened room was always physically at the same distance (25 feet) and was observed monocularly through a reduction tube originating in a lighted observer compartment. The different groups gave average results which were close to the physical distances at which a 12 inch ruler would have to be placed to subtend the particular visual angles. This study supports the point-of-view that the retinal size of a familiar object can be a determiner of perceived absolute distance. It was noted, however, that the inter-subject variabilities for the distance estimates were large (standard deviations of 5.6, 7.3, and 42.6 feet associated with the mean distance estimates of 14.3, 24.0, and 48.2 feet respectively) It is unlikely that the perception of absolute distance from familiar or assumed size occurs with sufficient precision to provide an explanation for the perception of relative depth from familiar or assumed size.

It was pointed out in the study by Gogel, et al., (1957) and also in the study by Baird (1963) that, since size comparisons can occur over time, it is difficult to measure perceived absolute distance uncontaminated by successive size comparisons. Probably, the time separation between the previous visual experience and the judgments in the test situation should be as long as possible. It is, however, important to determine the limiting conditions under which judgments of absolute distance can occur to further examine if indeed perceived absolute distance can provide a basis for the explanation of perceived relative distance (Gogel, 1963). The study by Gogel, et al., (1957) directly indicates that the perceived relative distance resulting from size comparisons can occur independently of perceived absolute distance. If this conclusion is correct, it follows that the psychophysics of perceived relative distance needs to be re-examined.

The Measurement of Perceived Relative Distance with a Comparison Field

It is probable that the "thereness – thatness" apparatus does not measure the perceived absolute distance of familiar objects. It is equally unlikely that it measures the perceived relative distance of familiar objects. Consider the case in which two familiar objects are viewed monocularly in a visually reduced experimental field with the perceived depth between the two objects measured by the physical distance between their apparent positions in a full-cue comparison field. Each of the familiar objects in the experimental field would subsequently appear at the distance of that portion of the comparison field which has the same value of S'/θ as the familiar object. Again, only apparent equidistance judgments would be required by *O*. It follows that the physical distance between the positions of the objects in the comparison field which appeared equidistant to the familiar objects in the experimental field would not be a valid measure of the perceived distance between the experimental objects. According to this point-of-view *O* has matched S'/θ values between each experimental object and portions of the comparison field. The perceived depth between the two experimental objects has not been represented in *O*'s performance and consequently has not been measured.

Attempts to measure the perceived relative depth between two *non-familiar* objects by means of a comparison visual field also introduces problems. Suppose, in the previous example, that two luminous squares of different retinal size are used instead of the familiar objects. Under these conditions, the retinally smaller square will appear to be the more distant square. But, what will be the perceived depth between the squares? The squares by themselves provide no scale or metric by means of which such judgments can be made. An *O*, if asked to make a relative depth judgment without the comparison field present, may do so. But it is doubtful whether such a judgment can be meaningful. However, Epstein and Baratz (1964) have found that *O*s can adjust two objects in a comparison field to the apparent radial distance of each of the two simultaneously presented, experimental squares of different retinal size. The distance between the two adjustments was interpreted to be a measure of the perceived depth between the squares. Evidently, the comparison field introduced a metric which was not in the original perception. Perhaps even more difficult to understand is the finding that non-familiar experimental objects such as ink blots, diamond shaped figures (Ittelson, 1951c) or discs (Epstein, 1961, Experiment II) *presented singly* will have an apparent localization with respect to the comparison field which changes systematically as a function of their retinal size. In this latter case, however, it has been found (Epstein, 1961, Experiment III) that the systematic change is considerably reduced when different groups of *O*s are used with the different retinal sizes. When the same *O*s are used with different retinal sizes, it seems that a perception of relative not absolute distance is being measured as a consequence of the successive presentations. A possible explanation of how a perception of relative distance can result from a retinal size difference between successively or simultaneously presented non-familiar objects as a consequence of the presence of a comparison field is as follows: It is very difficult to eliminate all extraneous factors (factors other than the cue system being studied) which can relate the depth position of one or more of the experimental objects with respect to the comparison field. It has been found, for example, that the accommodative differences between the experimental and comparison fields by itself sometimes can determine the apparent depth position of the experimental object (Gogel, 1961). Also, even when the difficult task of completely eliminating extraneous cues is accomplished, factors such as the equidistance tendency (Gogel, 1956b) probably would result in some localization of the experimental objects with respect to the comparison field. Assume that one of the discs, or squares, or ink blots as a consequence of extraneous factors will appear to be located somewhere in depth with respect to the comparison field. It follows that the S'/θ value associated with this apparently equidistant portion of the comparison field will become the S'/θ value of the object. In other words, the disc, or square, or ink blot will acquire a perceived size. Then, as a result of shape identity, the other disc, or square, etc., (either simultaneously or successively presented) will acquire the same perceived size. Each of the pair of squares, etc., will thus acquire an S'/θ value and, therefore, a specific perceived relative depth. Consequently, the perceived relative depth measured between non-familiar objects using a comparison field is probably not independent of the comparison field. If the above explanation is correct, however, the perceived depth which is measured, in this case, probably is less contaminated by the measuring (comparison) field than is likely in the case of familiar objects.

Possible Relations Between Perceived Distance and S'/θ

An Application of the Size-Distance Invariance Hypothesis

A conclusion of this paper is that the perceived relative depth between objects resulting from size cues is some function of the S'/θ values of the objects. It is asserted that the variable S'/θ applies to both relative and familiar size cues so that these seemingly different types of size cues involve the same basic process. The task remains, however, of determining the specific relation between d' and values of S'/θ. One suggestion for this relation comes from the size-distance invariance hypothesis (cf., Kilpatrick & Ittelson, 1953) of which perceived size as a cue to distance is a particular case (Epstein, Park, & Casey, 1961). The size-distance invariance hypothesis can be expressed (Kilpatrick & Ittelson, 1953; Gogel, 1964b) as

$$D' = \frac{1}{K_1}\frac{S'}{\theta}, \qquad (1)$$

where K_1 is a constant for a particular observer or situation. Equation (1) states that a particular value of retinal size (θ) and a particular value of perceived size (S') determines a particular perceived absolute distance (D'). Also, according to Equation (1),

$$d'_{ef} = \frac{1}{K_1}\left(\frac{S'_f}{\theta_f} - \frac{S'_e}{\theta_e}\right), \qquad (2)$$

where $d'_{ef} = D'_f - D'_e$. From the previous discussion, the use of a comparison field, for the measurement of the perceived distance of familiar experimental objects, results in apparent equidistance adjustments as determined by equal values of S'/θ of the experimental and comparison objects. A review of the available evidence will demonstrate that when a comparison field is used the resulting data are in agreement with Equation 1. However, it will also be asserted that such agreement would occur whether Equation 1 is valid or not.

Suppose that a double-sized playing card (17.8 cm. high) is presented at 304 cm. in an experimental field and its apparent distance measured with a comparison field. The double-sized card usually will appear to be 8.9 cm. high (its normal height) and will subtend a visual angle of .058 radians. It follows that the S'/θ value of the playing card is 152 cm./radian. The comparison field is a full cue situation such that the objects comprising the comparison field will be perceived to be their physical size. Therefore, an object, for example, a square, 8.9 cm. high, at 152 cm. in the comparison field will appear to be 8.9 cm. high, will subtend a visual angle of .058 radians, and will have an S'/θ of 152 cm./radian. Since the square and the playing card have equal S'/θ values, the playing card will appear to be at the same distance position as the square in the comparison field. As is the practice when using comparison fields, the 152 cm. distance of the square from *O* would be taken to be a measure of the perceived absolute distance of the playing card. Actually the playing card in the experimental field might have been perceived by *O* at any or no absolute distance without changing the measured result. The unwarranted conclusion would be made that the double-sized playing card physically located at 304 cm. actually appeared to *O* to be 152 cm. from himself. From the results of such measurements, the unwarranted conclusion would be drawn that familiar objects of particular retinal sizes will be perceived to be at distances which normal-sized objects of that familiar category would have to occupy in order to produce the particular retinal sizes. This is also the conclusion which would be predicted from Equations 1 or 2 when $1/K_1 = 1$. Therefore, the use of comparison fields should result in Equations 1 or 2 being satisfied regardless of the validity of these equations.

In Equation 1, measurements of S', D', and θ should reflect the perceived size, the perceived distance, and the visual angle, respectively, of the experimental object. However, according to the point-of-view of this paper, when the "thereness—thatness" apparatus is used, the experimental object will appear equidistant with that object in the comparison field which has the same value of S'/θ as does the experimental object. Furthermore, the rationale of using comparison fields requires that the *physical distance* of this apparently equidistant object in the comparison field be taken as the *perceived distance* of the experimental object. Therefore, S' and θ refer to events in both the comparison and experimental fields while D' is measured by D in the comparison field. Equation 1 can be put in the form

$$\frac{S}{D} = \frac{1}{K_1}\frac{S'}{D'} \qquad (3)$$

where $S/D = \theta$ in radians. But if D' is assumed to be measured by D in the comparison field, it follows from Equation 3 that the only requirement in order for $1/K_1$ to equal unity in Equations 1 and 2, is that S' is proportional to S in the comparison field. This condition might be termed the condition of veridicality of perceived size in the comparison field, i.e., perfect size constancy in the comparison field. It follows that, if perfect size constancy occurs in the comparison field, and if the judgmental process involves only the comparison of S'/θ values between experimental and comparison objects, the data obtained from using the comparison field should have the slope $1/K_1 = 1$, when D' is plotted against S'/θ with θ expressed in radians. If this reasoning is correct, the results from using a comparison field are likely to measure the amount of size constancy in the comparison field rather than the perceived absolute distance of the experimental object. It will be noted that a value of $1/K_1 = 1$ in Equations 1 and 2 would also be expected if the familiar object would be perceived at a distance which a normal-sized object of that particular category would have to occupy to subtend the particular retinal size, i.e., if the retinal size of a familiar object were a veridical cue to perceived absolute distance.

Figure 3 shows the relation between D' and S'/θ from three experiments in which a "thereness—thatness" type of apparatus was used. The solid line in Figure 3 represents the results which would be expected if the data fitted Equation 1 exactly and if $1/K_1$ were unity. However, any series of data points which describe a linear function passing through the origin of Figure 3 would satisfy Equation 1 with the slope of the function determining $1/K_1$. The triangular data points in Figure 3 represent the average results from successively presenting three different retinal sizes of a playing card to the same group of observers in a study by Ittelson (1951c, Experiment II). In

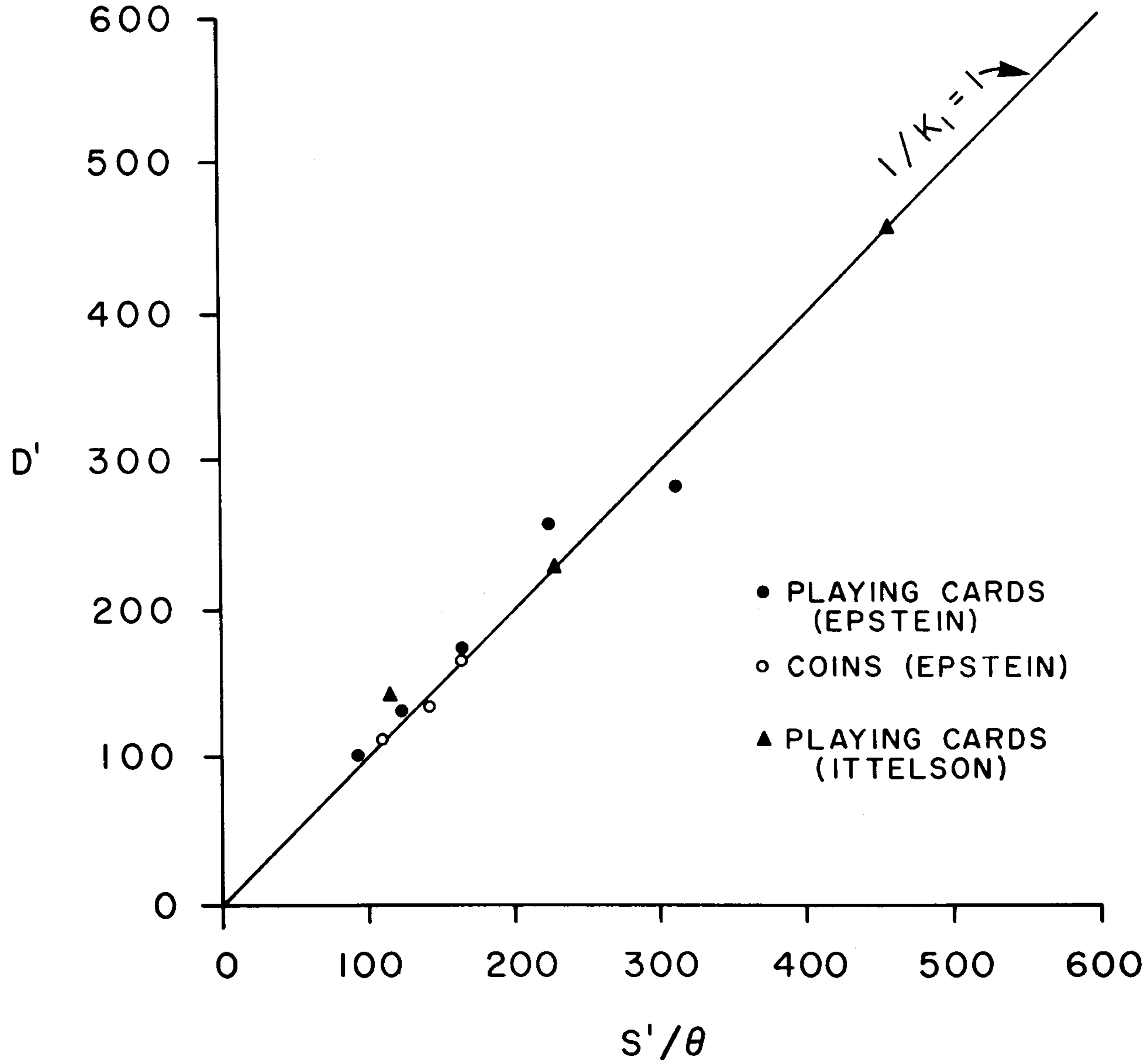

Figure 3. (Data from Ittelson, 1951c, Experiment II; Epstein, 1961, Experiment I; and Epstein, 1963). The relation between perceived distance (D') and perceived size per unit of retinal size (S'/θ) of playing cards and coins, determined by using a comparison field. The terms D' and S' are in centimeters and θ (visual angle) is in radians.

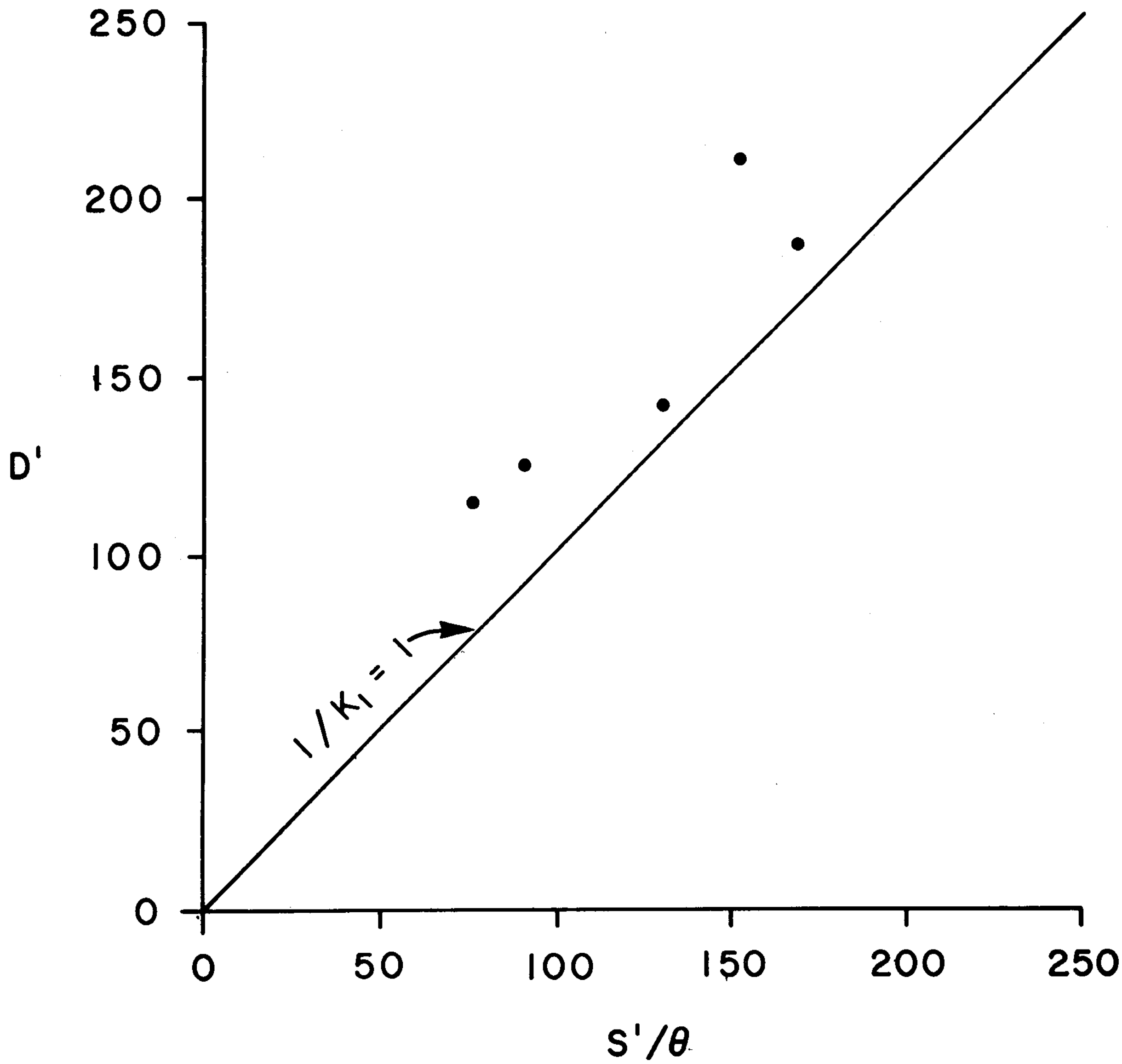

Figure 4. (Data from Epstein, 1961, Experiment II). The relation between perceived distance (D') and perceived size per unit of retinal size (S'/θ) of colored discs, with S' and D' measured by using a comparison field. The terms D' and S' are in centimeters and θ (visual angle) is in radians.

order to calculate S'/θ for this study, it was assumed that S' was 8.9 cm. (the height of a normal-sized playing card). The average data are very close to the line representing $1/K_1 = 1$. The filled circular data points in Figure 3 give the average results from a control group of *O*s in an experiment by Epstein (1961, Experiment I) when playing cards of different angular sizes were presented successively with measurements taken of both apparent size and apparent distance. In spite of the factor of familiar size, the cards were not always perceived to be of the same size. Nevertheless, the data reasonably fit the line representing $1/K_1 = 1$ in Figure 3. From the viewpoint of the present paper the results from both of these studies are interpreted to mean that the cards were perceived to be located at those distance positions in the comparison field at which the comparison and experimental objects had equal values of S'/θ and that, as might be expected, perceptions of size in the comparison field were essentially veridical. When the perceived size S' of the playing card in the experimental field differed from that expected from familiar size, the perception was in agreement with the S'/θ value, not in agreement with familiar size. The unfilled circular data points in Figure 3 are the average results from the study by Epstein (1963) in which figures of different kinds of coins with different assumed sizes but with constant retinal sizes were presented singly to different groups of *O*s. Pinhole viewing was used to eliminate accommodation as a distance cue. Both the sizes and the distances of the coins were judged. The judged size of the coins was close to that of normal-size coins of the particular denominations. The average data lie near the solid line representing $1/K_1 = 1$ in Figure 3.

Equation 1, with a value of $1/K_1 = 1$, also can be approximately satisfied when non-familiar objects are used in the "thereness—thatness" type of apparatus. This is indicated by the results obtained with non-familiar objects in the study by Ittelson (1951c) and also by Figure 4. The data points of Figure 4 are the average results from an experiment in which different discs of different colors and different angular sizes were presented one at a time to the same group of *O*s with observer judgments made of both the sizes and distances of the discs (Epstein, 1961, Experiment II).

It seems that the data of both Figures 3 and 4 are in agreement with Equation 1 since essentially the data points seem to lie on a straight line passing through the origin. But, the data do more than satisfy Equation 1 in general. Specifically, the data lie close to the line specified by $1/K_1 = 1$. These results would be expected if, as this paper asserts, the *O*s (regardless of their intentions) were matching S'/θ values between the experimental object and objects in a veridically perceived comparison field instead of judging the absolute distances of the experimental object. Either this interpretation or Equation 1 is adequate for all the results shown in Figures 3 and 4. The interpretation that the standard objects were perceived at absolute distances, consistent with normal-sized objects of the particular retinal sizes, is appropriate to the triangular and open circle data points of Figure 3, but is not relevant to the remaining data of Figure 3, or to the data of Figure 4.

If the use of comparison fields is not an appropriate method of testing Equations 1 and 2, and if Equations 1 and 2 are not valid, methods of measuring perceived depth from size cues which do not use comparison fields should give results in disagreement with these equations. Results from several studies pertinent to this problem are shown in Figures 5, 6, and 7. In Figure 5, the D' values are the average dart throwing and verbal reports in centimeters from the study by Gogel, et al., (1957) in which playing cards of different retinal sizes were presented one at a time to four different groups of 20 *O*s. The S' values used in computing S'/θ in Figure 5 are assumed to be the height of an ordinary playing card (8.9 cm). The line labeled $1/K_1 = 1$ again represents Equation 1 with $1/K_1$ equal to unity. The results from cards at different distances but subtending the same visual angle are averaged in Figure 5. The curves labeled "first presentations" give the average results from the first presentations of the cards. These results are concerned with perceived absolute distance. The results from all presentations of the cards

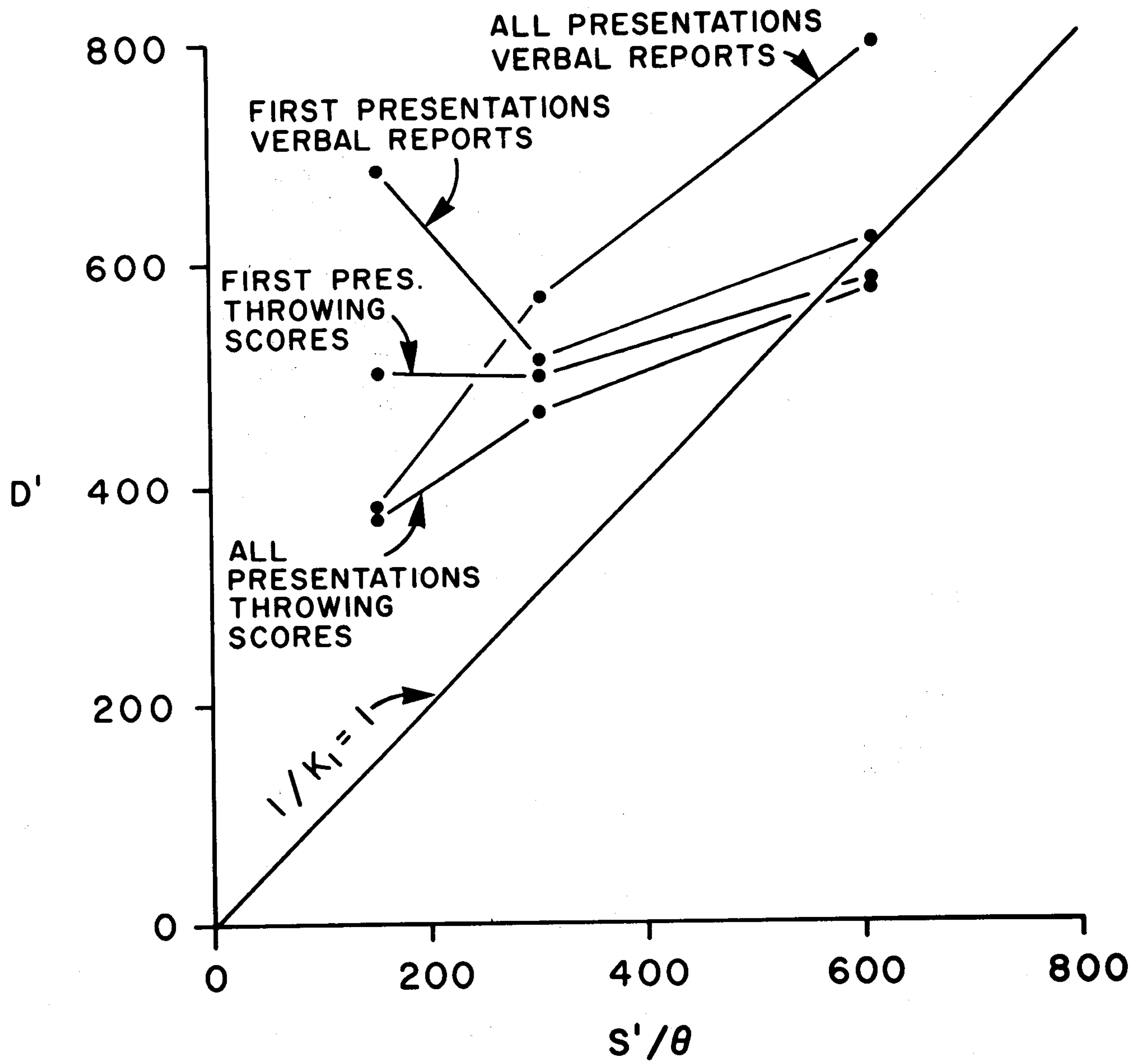

Figure 5. (Data from Gogel, et al., 1957). The relation between verbal and throwing measures of perceived distance (D') and values of perceived size per unit of retinal size (S'/θ) for both the initial and successive presentation of playing cards. The value of S' is assumed to be constant for all the presentations. The terms D' and S' are in centimeters with the value of S' set equal to 8.9 cm., the height of a normal-sized playing card. The term θ (visual angle) is in radians.

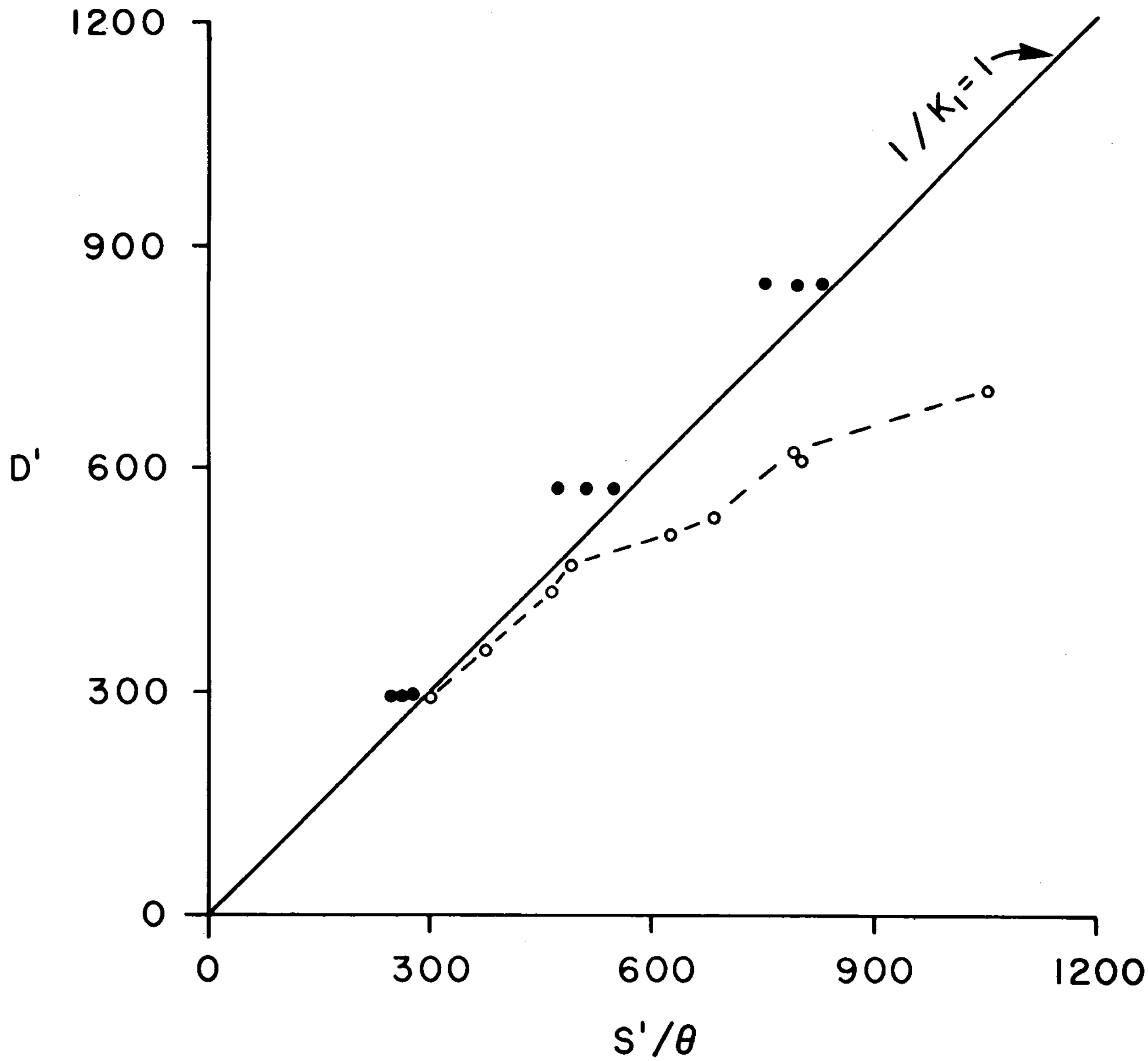

Figure 6. (Data from Over, 1963). The relation between perceived distance (D') and perceived size per unit of retinal size (S'/θ) as obtained from verbal estimates of the size and distance of diamond-shaped figures. The terms D' and S' are in centimeters and θ (visual angle) is in radians.

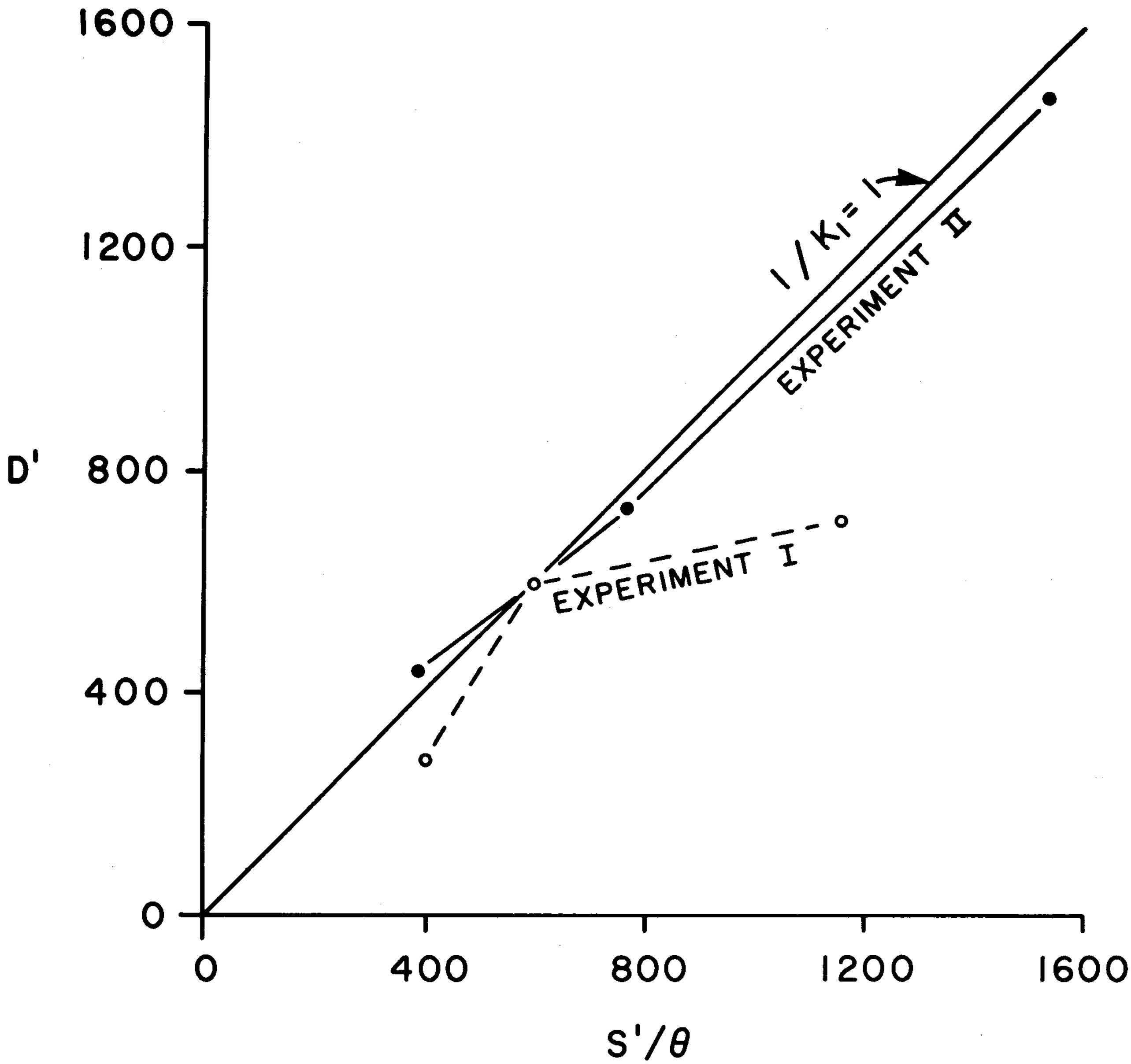

Figure 7. (Data from Baird, 1963). The relation between perceived distance (D') and perceived size per unit of retinal size (S'/θ) as obtained from size and distance estimates (Experiment I) or distance estimates (Experiment II) of triangular or rectangular figures. The terms S' and D' are in centimeters and θ (visual angle) is in radians.

are given in the curves labeled "all presentations". These latter results represent relative distance judgments as a function of the successive presentation of the cards to the same group of *Os*. It seems that none of the data curves of Figure 5 fit Equation 1. They either seem to be non-linear, or if extrapolated would not pass through the origin as Equation 1 requires.

In a study by Over (1963), 4 *Os* made 90 verbal judgments of the size and distance of diamond-shaped figures (squares) of different physical sizes presented successively at various distances under reduced viewing conditions, i.e., with no size or distance cues present except the size cue between successive presentations. Following this, the same *Os* repeated the judgments under unrestricted viewing conditions, i.e., conditions in which many size and distance cues were available. Since the same *Os* were used for the successive presentations, the judged distances in the reduced cue situation probably were not perceived absolute distances. However, the differences between pairs of distance judgments can be interpreted as representing perceived relative distances. No perceptual scale was available under the reduced cue conditions and it is, therefore, unlikely that the magnitude of any single perceived relative distance was meaningful. However, changes in perceived relative distance as a function of changes in relative retinal size would be meaningful data. The results from the reduced and the unrestricted viewing conditions are given by the open and filled-in data points, respectively, of Figure 6. The solid line curve of Figure 6 again represents Equation 1 with $1/K_1$ equal to unity. The judgments made in the reduced cue conditions clearly are not in agreement with Equation 1. As shown by the dashed line curve, judgments made in the reduced cue conditions appear to determine a curvelinear rather than a linear function. The judgments made under the unrestricted viewing conditions involved many cue systems in addition to that of size. The data from the unrestricted viewing conditions, as expected, are close to the curve labeled $1/K_1 = 1$. The unrestricted viewing data are not pertinent when considering the function involved in perceived size as a cue to distance. However, judgments from the unrestricted viewing conditions do demonstrate that the method of judging size and distance used in the study was valid and reliable. It follows that the curvelinearity of the "reduced viewing" function cannot be attributed to a non-linear scale inherent in the method of measurement and, therefore, the results from the reduced viewing conditions represent valid evidence against Equation 1 (and 2).

Average data from a study by Baird (1963) are presented in Figure 7. The curve labeled "Experiment II" concerns the verbal reports of the distance of a rectangular figure designated as the size of a 12 inch ruler. Different retinal sizes of this figure were presented to different groups under reduced conditions of observation, with ten *Os* in each group. It will be noted that the curve labeled "Experiment II" differs considerably from the first presentation curves of Figure 5 and is essentially in agreement with Equation 1, with $1/K_1 = 1$. The curve in Figure 7 labeled "Experiment I" refers to the average results from another experiment by Baird in which different assumed sizes were induced in a triangle of constant retinal size by first showing rectangles of differing angular size with each rectangle designated as being 12 inches wide. Only the results obtained under objective instructions were used in Figure 7. Size judgments were made by using a comparison triangle, and distance judgments were made verbally. Most likely, the curve labeled "Experiment I" of Figure 7 represents relative judgments of size and distance. Since the distance judgments for the middle and small retinal sizes were greater than the distance to the comparison object it is likely that the comparison field could not completely determine the distance judgments. Obviously the "Experiment I" curve does not fit Equation 1. Also, the "Experiment II" curve is essentially linear while the "Experiment I" curve is not. Experiments I and II by Baird are considered to measure perceived relative and perceived absolute distance, respectively. However, if the curve for perceived absolute distance is linear, the curve for perceived relative distance according to Equation 1 should be linear also. Although the curves in Figure 7 are considerably different from those in Figure 5, both Figures 5 and 7 can be interpreted as indicating that perceptions of relative distance from size cues are not always explainable in terms of differences between perceptions of absolute distance.

In Figures 5, 6, and 7 only the "Experiment II" curve of Figure 7 supports Equation 1. The curves in Figures 5, 6, and 7 which do not support Equation 1, also do not support Equation 2. However, there are several studies which directly have measured d' rather than D' as a function of size cues. An experiment which can be applied here is the experiment by Ittelson (1951b, Experiment II) in which three playing cards of different physical sizes were moved, one at a time, a constant distance toward and away from *O*, in a visually reduced experimental field. Using a comparison field, five *O*s judged the nearest and farthest positions of the movement for each of the physical sizes of the card. Physical distance between these judgments can be taken as d', θs can be calculated from the physical sizes and the physical distances of the near (e) and far (f) positions, and S' can be assumed to be the size of a normal playing card. The results from plotting the average values of d' against differences in S'/θ are shown by the curve containing data points in Figure 8. The straight line labeled $1/K_1 = 1$ again represents the results expected if $1/K_1$ in Equation 2 were unity. The data curve of Figure 8, although linear with a slope of approximately unity, does not pass through zero as Equation 2 requires. Either the data do not support Equation 2 or the discrepancy is a consequence of interactions between the experimental and comparison fields. In the study by Epstein and Baratz (1964, Experiment II) a comparison field was used to measure the perceived depth between pairs of simultaneously presented coins with each coin subtending one of three possible retinal sizes. Thirty-two *O*s adjusted two nonsense-form comparison figures to duplicate the apparent distance between each of the pairs of coins. The radial difference between the adjustments in the comparison field for each pair of coins was considered to be the perceived depth d' between the pairs of coins. Figure 9 shows the obtained relation between d'_{ef} and $S'_f/\theta_f - S'_e/\theta_e$, with each data point being the average result from a particular pair of coins. The values of S' used in determining S'/θ in Figure 9 were obtained from the average apparent sizes of monocularly observed coins obtained under similar conditions in a previous study by Epstein (1963, Table II). From Figure 9 it is clear that the perceived depth between coins (as measured in the comparison field) and the algebraic difference between values of S'/θ are related ($r = .90$) and in general satisfy Equation 2 with $1/K_1 = 1$ (although there is possibly some tendency for the relation to be nonlinear for large differences in S'/θ). Again, these results can be interpreted either as valid evidence for Equation 2 (and 1) or, as an artifact resulting from the use of a comparison field. In a recent study, Epstein (1964), using a comparison field, had 18 *O*s adjust nonsense-form comparison figures to duplicate the apparent depth between simultaneously presented pairs of non-familiar, luminous squares of different retinal sizes presented in a dark experimental field. The radial difference between the adjustments in the comparison field for each pair of squares was considered to be the perceived depth (d') between the pairs of squares. Since the squares were non-familiar objects, the physical sizes of the squares cannot be considered to represent their perceived sizes. Therefore, S' is unknown and the value of K_1 in Equation 2 cannot be determined from the data of this experiment. However, d' can be plotted as a function of $1/\theta_f - 1/\theta_e$ as shown in Figure 10. If, as is reasonable, it is assumed that S' is a constant throughout this experiment, a linear curve fitted to the data of Figure 10 should pass through the origin if Equation 2 is valid. It follows that the data of Figure 10 do not support Equation 2.

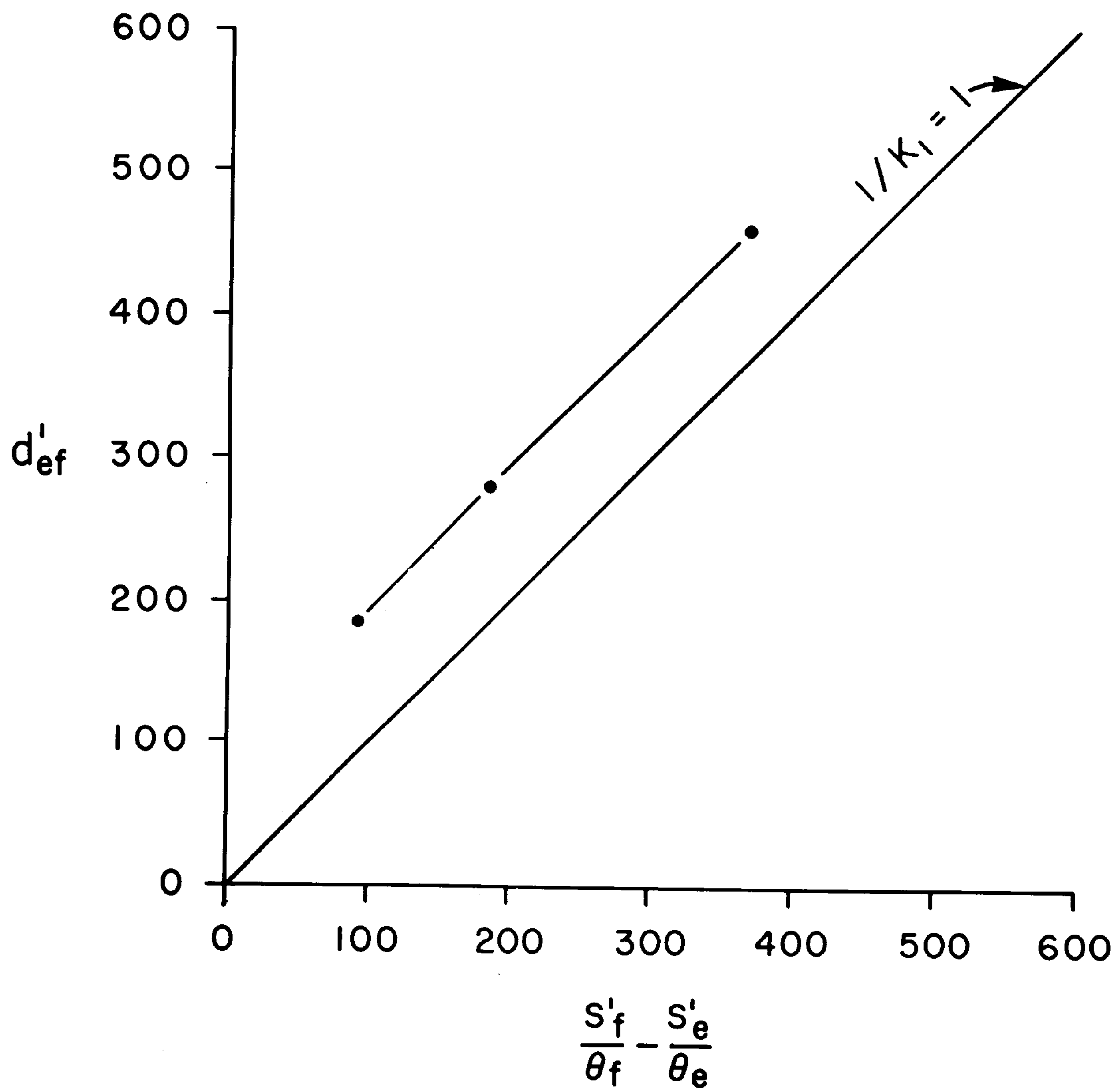

Figure 8. (Data from Ittelson, 1951b, Experiment II). The relation between perceived relative distance d'_{ef} and differences between perceived sizes per unit of retinal sizes $(S_f/\theta_f - S'_e/\theta_e)$ for different sizes of moving objects with d'_{ef} measured by using a comparison field. The terms d'_{ef}, S'_e, and S'_f are in centimeters. The terms θ_e and θ_f are visual angles expressed in radians.

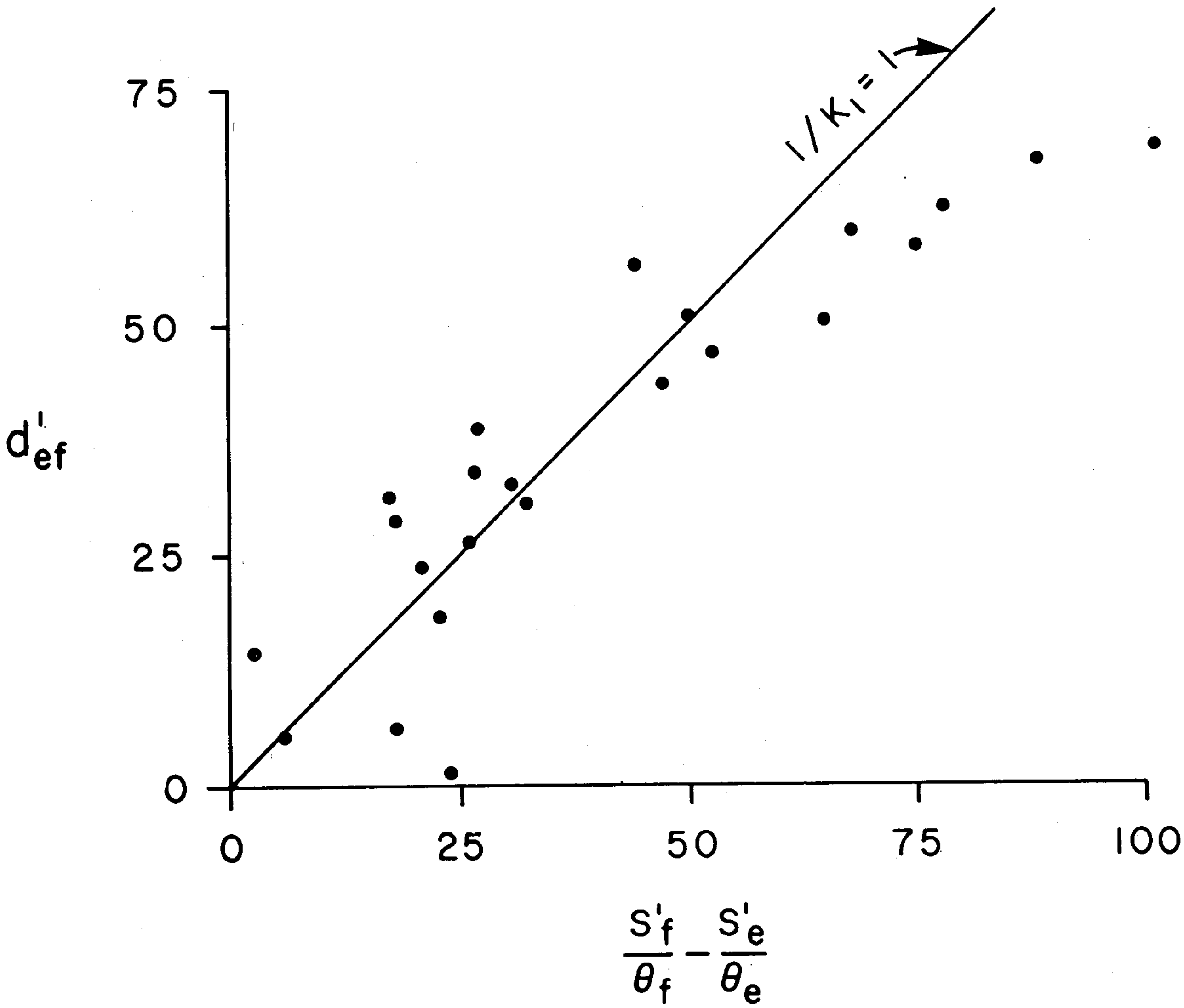

Figure 9. (Data from Epstein and Baratz, 1964). The relation between perceived relative distance d'_{ef} and differences between perceived sizes per unit of retinal sizes ($S'_f/\theta_f - S'_e/\theta_e$) for pairs of coins with the perceived extents measured by using a comparison field. The terms d'_{ef}, S'_e, and S'_f are in centimeters. The terms θ_e and θ_f are visual angles expressed in radians.

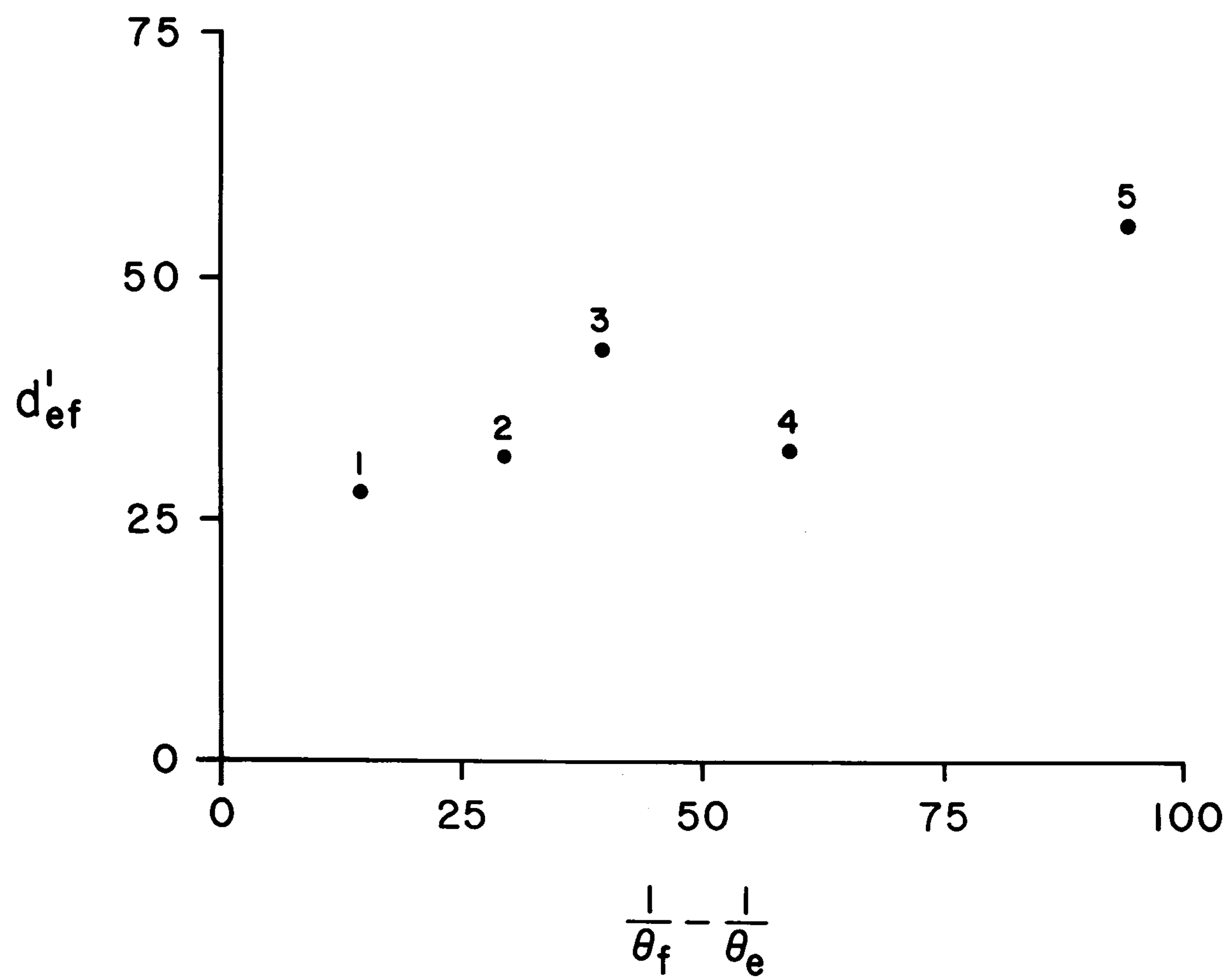

Figure 10. (Data from Epstein, 1964). The relation between perceived relative distance and differences between reciprocals of retinal sizes for pairs of squares, with the perceived depth measured by using a comparison field. The value of S' of the squares is assumed to be constant throughout the experiment. The term d'_{ef} is in centimeters. The terms θ_e and θ_f are visual angles expressed in radians.

Retinal Size Ratios as Size Cues to Relative Distance

Based upon the conclusions that perceptually significant cues (a) involve relative rather than absolute retinal size and (b) occur between adjacent rather than displaced objects, it has been suggested (Gogel, 1963, p. 116) that "ratios of θs rather than θs *per se*" are the retinal stimuli for the relative size cue to relative depth. According to this point-of-view, two perceived depth intervals d'_{ef} and d'_{gh} would be perceived as equal, using the relative size cue with non-familiar objects, only when the ratios of the retinal sizes between each pair of objects were equal. That is, assuming that $S'_e = S'_f = S'_g = S'_h$,

$$d'_{ef} = d'_{gh} \text{ only when } \theta_e/\theta_f = \theta_g/\theta_h. \quad (4)$$

Equation 4 can be contrasted with Equation 2, with the latter stating that if $S'_e = S'_f = S'_g = S'_h$

$d'_{ef} = d'_{gh}$ only when

$$1/\theta_f - 1/\theta_e = 1/\theta_g - 1/\theta_h. \quad (5)$$

The pairs (e and f) of retinal stimuli involved in the data points labeled 1, 2, and 4 in Figure 10 produced a constant ratio of retinal sizes θ_e/θ_f and, as shown on the ordinate, resulted in a nearly constant value of perceived depth d'_{ef}. It was concluded by Epstein (1964) that the results from this study support the hypothesis that the perceived depth between the pairs of objects was determined by the ratio of their retinal sizes. Within the limitations involved in the use of comparison fields for the measurement of depth between non-familiar objects, this conclusion supports Equation 4. An equation relating d' and size cues probably should satisfy at least the following conditions: (1) The requirement that S'/θ is the significant variable in the size cue to relative depth; (2) The requirement that d' is zero, positive, or negative when S'_e/θ_e is equal to, less than, or greater than S'_f/θ_f, respectively; (3) The probability that ratios of θs rather than θs *per se* are the perceptually significant stimuli; (4) The probability that D' is a negatively accelerated function of S'/θ. An example of one of the simplest equations satisfying these requirements is

$$d'_{ef} = \frac{S'_e}{T} \ln \frac{S'_f/\theta_f}{S'_e/\theta_e} \quad (6)$$

where T is an observer constant. Equation 4, for example, can be derived directly from Equation 6. It is obvious, however, that additional research will be required, and preferably by methods other than those using comparison fields, before the psychophysical function of the size cue to relative depth can be specified with confidence.

Concluding Remarks

It is concluded that both perceived size S' and retinal size θ are involved in both the relative (retinal) size cue and the familiar size cue to relative depth. Furthermore, it is asserted that these two factors are the only factors involved in the size cue to relative depth. When the two factors S' and θ are expressed as the ratio S'/θ they can be shown to be applicable to any objects regardless of the shape or complexity of the objects. It is clear that, from this point-of-view, size cues to relative depth occur, for example, between a rock and a tree as well as between two playing cards or other symmetrical objects. The S'/θ value of each of the two (or more) objects must be considered in predicting the perceived depth which will occur between them. It remains to specify the exact relation which occurs between perceived depth and the relative values of S'/θ. The evidence that the size-distance invariance hypothesis in its usual form can specify this relationship at first appears conclusive. However, much of the evidence for this conclusion was obtained by using comparison fields for the measurement of perceived distance. It is asserted that the use of a comparison field introduces an artifact in the measurement of perceived depth from the size cue. An analogous case would be an attempt to measure the effect of the convergence of the eyes on perceived distance by measuring the perceived position of a binocularly observed, experimental object with respect to a binocularly observed, comparison field. The experimental object would appear equidistant with that object in the comparison field with respect to which its binocular disparity was zero. Clearly, this result would have no bearing on the possible relation between convergence and perceived distance. Similarly, an experimental object with a particular value of S'/θ will appear equidistant with that object in the comparison field which has the same value of S'/θ. This result has no bearing upon whether familiar size is a cue to perceived absolute distance or, more generally, no bearing upon the validity of the size-distance invariance hypothesis (Equation 1). Equation 1 as it applies to size cues may be correct. But, such a conclusion cannot be made with confidence on the basis of evidence resulting from the use of comparison fields. Futhermore, there is some evidence which indicates that, contrary to Equations 1 (and 2), the perceived distance resulting from size cues is not a linear function of S'/θ. An hypothesis which might be called the ratio hypothesis is tentatively suggested (Equation 6) as meeting certain requirements of the operation of the size cue to relative depth.

If, as seems likely, the perceptual effect of relative values of S'/θ can occur between the experimental and comparison field, even though the two fields are not presented simultaneously, the specification of comparison fields becomes more general. A comparison field is any visual field which *O* has observed prior to, or simultaneously with, the observation of the experimental object. It is also possible that a visual field which occurs following the presentation of the experimental object might affect the perceptions associated with the experimental object. This more general definition of comparison fields calls attention to the possibility that the occurrence of visual fields prior to the particular experiment can effect the perception of the distance or the size of the experimental object even though no comparison fields are presented in the experimental situation. As mentioned previously, however, it seems reasonable that the magnitude of the interaction between the experimental field and the comparison field (as defined either in the specific or more general sense) would be a decreasing function of the time intervals between their occurrences.

The importance of S'/θ is not limited to the specification of the size cue to relative depth. It has been demonstrated in several studies (Gogel, 1960; Gogel, 1964a) that the perceived depth from binocular disparity varies as a function of the S'/θ values in the perceptual vicinity of the objects producing the disparity. Therefore, the concept of S'/θ may be the concept which relates the binocular disparity and size cue systems. If so, it is likely that the prevalent distinction between these two systems as primary and secondary cues is inappropriate since both cue systems are subject to the operation of a common factor.

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