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The independence of size perception and distance perception

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Research on distance perception has focused on environmental sources of information, which have been well documented; in contrast, size perception research has focused on familiarity or has relied on distance information. An analysis of these two parallel bodies of work reveals their lack of equivalence. Furthermore, definitions of familiarity need environmental grounding, specifically concerning the amount of size variation among different tokens of an object. To demonstrate the independence of size and distance perception, subjects in two experiments were asked to estimate the sizes of common objects from memory and then to estimate both the sizes and the distances of a subset of such objects displayed in front of them. The experiments found that token variation was a critical variable in the accuracy of size estimations, whether from memory or with vision, and that distance had no impact at all on size perception. Furthermore, when distance information was good, size had no effect on distance estimation; in contrast, at far distances, the distances to token variable or unknown objects were estimated with less accuracy. The results suggest that size perception has been misconceptualized, so that the relevant research to understand its properties has not been undertaken. The size–distance invariance hypothesis was shown to be inadequate for both areas of research.

Theorists have assumed that similar processes are used to perceive both the size of an object (how big a static object is in a metric sense in three-dimensional space) and the distance of an object (how far away a static object is from the observer in three-dimensional space). As a result, theories of size and distance perception are so intertwined that questions of the independence of these two perceptual processes are typically unanswerable (see Gillam, 1995, 1998, for recent discussions). Furthermore, progress in our understanding of these two processes is quite unbalanced.

Nearly two centuries of research has focused on distance perception, resulting in a nearly complete description of the sources of information and processing mechanisms that human observers depend on for their perception of distance (see Cutting & Vishton, 1995; Haber, 1983; and especially, Sedgwick, 1986). In contrast, size perception (see Hershenson, 1999) has not received comparable attention in the research literature (including even size constancy; see Epstein, 1961, 1977). As a consequence, explanations of the sources of information and processing mechanisms that human observers depend on for the perception of size have been very unsatisfying and share nothing of the complexity and completeness of the comparable descriptions for distance perception.

Why the disparity? We have argued (Haber & Levin, 1989) that theorists have failed to recognize that distance perception and size perception not only serve very different perceptual demands, but have failed to recognize that they depend on largely nonoverlapping sources of information. From these initial failures, theorists have been led to relate the two processes inappropriately, to the great detriment of understanding one of them.

With respect to perceiving the distance to an object, we argued that its primary functions are to support visually guided locomotion and to track moving objects in space (see also Cutting, 1998; Haber, 1986; Haber & Haber, 1991). Moving observers need to perceive the locations and distances to objects in the environment from an infinite variety of ego-locations and distances so as to be able to move among them safely and surely and to be able to avoid or catch those that are themselves moving. To do this, moving observers must depend on stimulus information that is only available at the time of the perception, such as combinations of concurrent stimulation originat-

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ing from the observer's physiological system, arising from static and dynamic visual stimulation reaching the eyes and from the consequences of observer-originated movements made while looking at the scene. Furthermore, since human beings must be able to move about in this vast variety of different scenes, this combination of stimulation should make relatively little demand on prior experience with the particular objects, paths, and obstacles in the scene. In fact, skill at distance perception and the use of distance perception to control visually guided locomotion, should develop and be available early in life and in tandem with maturation of locomotor abilities themselves: Learning, practice, experience, and memory should not be important components of explanations of distance perception. Specifically, familiarity effects based on prior contact or knowledge about the objects whose distances are being perceived should be irrelevant to determining the accuracy of that perception. We must be (and are) able to move easily and accurately in unfamiliar as well as familiar environments and among unfamiliar as well as familiar objects. There can be little substitute for concurrent perceptual processing occurring in real time.

In contrast, we have argued that size perception should function the other way around. Concurrent perceptual processes should be irrelevant (other than to allow recognition or identification of the object and perhaps to perceive its rigidity; see Hershenson, 1992). Once the object is identified, the perceiver has access to most of its properties (its character, its trustworthiness, the consequences of dropping or kicking it, its size, etc.). In this sense, "perceiving" the size of an object may be a misnomer: Rather, the observer identifies the object and then "remembers" its size (along with its other relatively constant characteristics) on the basis of prior encounters. Only for perception of completely novel objects that have never been encountered before would a concurrent perceptual process be required. Since entirely novel objects become increasingly rare as one acquires experience with the world, we have argued that size "perception" is a cognitive or memorial process, one that draws on quite different stimulus information and processing mechanisms for its accuracy than those underlying distance perception. Familiarity with the object (acquired from the past) should be the most important variable determining the accuracy of "perceiving" how big the object appears to be.

Familiarity as a variable in size perception has had a long history (see Hershenson, 1999, for a recent discussion; Hochberg, 1971, for an older one), and is typically accorded the most prominent role in how we "perceive" the size of an object. In contrast, familiarity as a variable is rarely mentioned with respect to distance perception (see Ittelson, 1960, for a few counter examples), except in unusual and ecological atypical experimental settings in which the normally predictive sources of distance information are impoverished or absent. Given the sharp difference in the importance of the role of familiarity in these two kinds of perceptions, its manipulation should provide a way to disentangle the determinants of the accuracy and metrical scaling properties of distance and size responses. This is the purpose of the present experiments.

However, to better control the separation of these theoretical processes, the familiarity variable itself, as it applies to size perception, must be described more completely than has been done in the past.

Consider the following logical observations. For object familiarity to be useful in a size perception context, four criteria must be met. (1) The current observation conditions must be sufficient to allow the observer to correctly recognize (or identify) the token of the object presently on display. (2) The observer must have retained in memory prior experience about the properties of the category or class of object. (3) This prior experience must include knowledge of the prototypic (average or typical) size of the objects in this category. This means that upon discovering that the object being observed is an "X", the observer knows that the typical *X* is a given size. (4) This prior experience must include knowledge of the amount of size variation to be expected among possible tokens of the object. This means that the observer has to know whether all instances of *X* are the same size, and if not, by how much they differ from each other.

Most research on size perception that includes a familiarity variable assumes (or assesses by questionnaire) that the "familiar" objects chosen for judgment are known to the observer. Thus, familiarity has been operationalized almost exclusively in terms of prior contact (Criterion 2), either throughout the lifetime of the observer, or through training manipulated in the experiment. To our knowledge, it has never been studied in terms of knowledge of the prototypic size of the object (Criterion 3) or in terms of knowledge of the amount of token variation (Criterion 4). The ability to recognize an object as being familiar (Criterion 1) is also usually assumed in most research, though it can pose a problem for small objects viewed at long distances.

Although knowledge of prototypic size (Criterion 3) might be part of the general knowledge picked up through prior experience (Criterion 2), knowledge of token variation among instances (Criterion 4) has never been defined theoretically or addressed experimentally, though its implications should be obvious from the work of Brunswik (1956) nearly a half century ago. Specifically, an object whose tokens are known to occur in a wide range of different sizes logically would not be very useful as a predictor of the size of the particular token on view at the moment, regardless of how familiar observers are with the class of objects.

To illustrate the potential interplay of Criteria 2, 3, and 4 in size perception research, suppose that natural objects in the real world are classified into one of two broad categories, defined by characteristics of the tokens of the objects. The first category contains *token invariant objects*, each of which has a highly constrained range of sizes among their exemplars. Regulation basketballs (except for women's professional games) fulfill this definition: The mean prototypic size (diameter) of regulation basket-

Table 1
Measured Heights and Cognitive Estimates of Heights of 30 Common Objects (all Units in Feet)

	Measured		Cognitive Estimates	
Object	Height	*SD*	Height	*SD*
Token Invariant Objects				
CARD TABLE	2.33	0.00	3.13	0.62
BASEBALL BAT	2.79	0.04	2.86	0.58
BASKETBALL	0.75	0.00	0.95	0.19
MILK BOTTLE	0.83	0.00	0.98	0.23
DOOR	6.51	0.05	6.55	0.87
BEER BOTTLE	0.63	0.04	0.63	0.16
BIKE	3.04	0.06	3.18	0.78
POP BOTTLE	1.00	0.00	1.11	0.24
SKI POLE	4.00	0.08	3.78	0.68
FILE CABINET	2.26	0.04	2.94	0.73
BOWLING BALL	0.50	0.00	0.80	0.22
AXE	2.93	0.07	2.59	0.78
TENNIS	2.26	0.02	2.12	0.51
GUITAR	3.26	0.04	3.13	0.65
JEANS	2.74	0.07	3.05	0.46
Token Variable Objects				
CHRISTMAS TREE	5.85	1.18	6.82	1.25
KIT. TRASH	2.37	0.57	2.48	0.70
SPEAKER	1.96	0.77	2.54	0.84
KIT. CHAIR	3.05	0.53	3.30	0.75
GLOBE	1.31	0.82	1.56	0.70
ROAD CONE	1.80	0.76	2.01	0.68
TABLE LAMP	2.50	0.46	1.97	0.78
TEDDY BEAR	1.44	0.36	1.24	0.67
ROCK. CHAIR	3.81	1.23	4.01	1.24
TRICYCLE	2.53	0.66	2.23	0.70
TV	2.02	0.69	2.18	0.73
SAW HORSE	3.06	0.64	3.41	1.71
RED WAGON	1.48	0.49	1.72	1.21
HOUSE PLANT	1.78	0.91	2.06	1.48
SCREEN	4.60	1.08	5.17	2.20

balls is 0.75 ft, and the standard deviation among exemplars is virtually zero (see Table 1 for a number of other examples). The very small size variance among tokens means that the prototypic size is likely to be representative of any exemplar encountered. The second category contains *token variable objects*, each of which can also be described by a prototypic (average) size, but each object has a much less constrained size range among its tokens (e.g., stereo speakers, Christmas trees, teddy bears—see Table 1 for other examples). Thus, knowing the prototypic size of token-variable objects does not predict the size of any particular exemplar.

The above classification of token variability is dependent on only the distribution of tokens in the environment—an ecological variable determined by natural processes, manufacturers' choices or regulations and standards. When observers become familiar with an object, their experience (Criterion 2) should allow them to learn or determine the prototypic size of the object (Criterion 3) and should allow them to learn or determine the amount of the object's token size variation in the environment (Criterion 4). If the observers determine that an object is of the token invariant class, size "perception" may simply involve object recognition and then recall from memory of the tightly constrained prototypic size. In contrast, if the observers determine that an object is of the token variable class, recall of the prototypic size provides much less size information of the exemplar by virtue of the observers' past experience, even though the amount of familiarity with specific objects in the second class may be equivalent to that of the first (by Criteria 2 and 3). If "size perception" depends on a memorial process, estimates of object size should be less accurate for token variable objects.

The discussion above expands the definition of familiarity in two directions: It distinguishes among objects themselves in terms of their token size variation as a characteristic of the natural world, and it includes as a characteristic of observers' knowledge about objects both their knowledge of prototypic size and their knowledge of token size variation.

In this paper, we report the results of two experiments that examined implications of this definition of familiarity. In Experiment 1, we asked subjects to make size judgments of familiar objects that differed in their token variation. The objects were not on view. The results validated the distinction among familiar objects on the basis of their token variation. In Experiment 2, we asked subjects to make both size and distance estimations of both unfamiliar and familiar objects that differed in their token variation, all of which were on view. In Experiment 2, we also varied viewing conditions to determine whether those conditions impacted accuracy of distance and size estimates in similar ways. The results showed that the underlying processing mechanisms of size and distance perception are quite different.

EXPERIMENT 1

Can object classes be subdivided into those that are token invariant and token variable? Do observers have and use this knowledge in making objective size estimations about such objects? To show the former, physical size measurements were made of at least 10 instances of each of a large number of classes of familiar objects. To show the latter, subjects were asked to make objective size judgments of these kinds of objects from memory in the absence of any concurrent perceptual information. (We followed a procedure first used by Bolles & Bailey, 1956, though they did not consider or manipulate token variation).

Method

Stimuli. The subjects were presented with a list of names of 50 common portable objects. A much longer list of potential stimuli was drawn up that the authors believed would be familiar to college students and would contain some objects that had very small token variation and others that would have large token variation. The list was pared to 50 by asking a group of experimental psychologist judges to rate the objects on familiarity (without reference to token variability). To include an object on the final list, these judges had to agree that an object would be highly familiar to undergraduate students. The resulting 50-item list contained all of those objects that produced high agreement among the judges.

Size measurement procedure. Next, we obtained physical size (height) measurements of as many of the 50 objects as we could reasonably sample. The heights of actual instances of these objects (to the nearest quarter inch) in their normal orientation were measured. We found the objects in a minimum of three different stores and measured at least 10 different instances of each object and (wherever possible) found at least 10 different brands, all in local retail stores in the greater Chicago area. The 30 objects are listed in Table 1, along with the mean and *SD* of each of their measured sizes.

The 20 objects not measured were excluded from subsequent study because we could not find a sufficient number of representative samples of them to measure. A few were also excluded when we realized (during the subsequent design phase of Experiment 2) that we would not be able to transport instances of them (e.g., a refrigerator) for the second experiment.

Subjects and size estimation procedures. The subjects were 109 male undergraduate students enrolled in an introductory psychology course at the University of Illinois at Chicago. The subjects participated as partial fulfillment of a course requirement. The stimulus questionnaire containing the names of the items to be estimated was included in a mass testing packet along with questionnaires constructed by five other experimenters that pertained to different experiments. Questionnaire packets were distributed at the end of a class session and were returned within 48 h.

On the questionnaire, the 50 objects were listed in random order, each followed by a line on which the subjects were to write the estimated height of that object. The instructions for answering the questionnaire were as follows: "Listed below are a number of common objects. Please estimate the height of each of these objects to the nearest inch. Please make your estimates in feet and inches. For objects such as a baseball bat or a broom, please estimate the height of them standing on end."

Results

Do tokens vary among common objects? Token variability was estimated from the *SD*s among the 10 to 25 physical measurements of each of 30 of the objects on the questionnaire that were measured. The *SD*s ranged from a minimum of 0.00 ft (for five objects) to a maximum of 1.23 ft. (Because subjects were asked to make their estimates in feet and inches, all measurement data are also reported in those units.) Post hoc examination of the *SD*s of these multiple height measurements showed that 15 of the 30 objects had *SD*s among the measured instances of between 0.00 and 0.08 ft. The standard deviations are listed in the second column of Table 1 in the first 15 rows (reordered from the actual questionnaire to reflect this post hoc distinction). The remaining 15 objects had *SD*s among measured instances of between 0.36 and 1.26 ft. These are listed in the remaining 15 rows.

Using this post hoc determination, we labeled the first 15 objects, those objects with the near-zero variances, *token invariant* objects and the remaining 15, those with larger variances, *token variable* objects.

As it turned out, there was no difference between the mean prototypic sizes of the two classes of objects. The mean measured heights were 2.38 ft versus 2.62 ft (as is shown in the second column of Table 1), which was not significant [$t(28) = 0.474, p > .10$].

Therefore, the answer to the first question is yes: We found that, among common objects likely to be familiar to college students, some truly had no variance among a large sample of their tokens, whereas others had substantial variation from instance to instance.

How accurate are size estimations from memory? The 30 size estimates made by each subject were compared with the respective 30 means of the physical size measurements of the actual objects using multiple regression analyses, one analysis for each of the 109 subjects.[1] The proportion of variance accounted for in cognitive estimated size by true size is

$$\text{cognitive estimated size} = \text{B (true size)},$$

a measure of the accuracy of estimating the sizes of these 30 objects.[2] This proportion is given by the multiple correlation R^2. The mean R^2 averaged over 109 subjects was .94 ($SE = 0.02$). The very high value indicates that the subjects' size estimates for each object were very similar to the prototypic (average) measured size of each object. The B value represents the slope of the regression equation. Mean B = 1.04 ($N = 109$, $SE = 0.03$). We tested the slope against a null estimate of 1.00, and found we could not reject the null hypothesis ($p > .10$).

Therefore, the answer to the second question is also yes: College students know the prototypic size of common objects with great accuracy. This great accuracy is found even though the objects were not observed at the time of size estimation.

Are subjects sensitive to an object's token variation? The between-subjects *SD*s of the size estimates of each object (each based on $N = 109$) are found in column 4 of Table 1. The range of these *SD*s among the 15 token invariant objects was 0.16 to 0.87 ft, with a mean = 0.51 ft, which was not significantly different from zero ($p > .10$). In contrast, the 15 token variable objects ranged in *SD*s from 0.67 to 2.20 ft, with a mean = 1.04 ft, which was significantly greater than zero ($p < .05$). The means of the two sets of *SD*s were significantly different from each other [$t(28) = 3.904, p < .001$].

Therefore, the answer to the third question is also yes: The subjects' responses differed depending on the token variability of the objects whose size they were estimating. They vary less among themselves in estimating the sizes of objects that have little token variation.

Do subjects estimate the size of token invariant objects more accurately? The 109 regression equations (based on all 30 objects) were recomputed separately first for the 15 objects classified as token invariant and then for the 15 objects classified as token variable. These 218 equations were first modeled nonlinearly and then redone following a linear model when none of the 218 interceptions or exponents were found to differ from zero or unity, respectively. Repeated measures analysis of variance (ANOVA) revealed that the accuracy (R^2) of the cognitive size estimates for the token invariant objects (mean $R^2 = .97$) was significantly greater than the accuracy of the cognitive size estimates for the token variable objects (mean $R^2 = .92$) [$F(1,108) = 38.79, p < .001$]. The two mean B (slope) coefficients (1.02 and 1.09, respectively) were not significantly different from each other ($p > .10$), nor were they different from unity ($p > .10$).

Therefore, the answer to the fourth question is also yes: When token variability is low, the subjects were significantly more accurate (higher R^2) in estimating the prototypic size of such objects from memory.

Does the scaling of remembered objective size estimations follow a ratio scale? The relationship between measured size and cognitively estimated size is linear (exponent of unity) with an intercept of zero and a regression coefficient of unity. Furthermore, there were no differences between the means of the measured physical sizes and the corresponding cognitive sizes of the objects. Because it can be assumed that measured (true) size follows a ratio scale, the findings conjointly indicate that the subjects were using a ratio scale of cognitive size that is equal to true feet and inches in making their cognitive size estimations. This is found even though the cognitive size estimations were made from memory, without the objects' being visually accessible.

Discussion

We briefly consider five topics.

Token variation is logically important. The common objects selected for the present study could be distinguished by the magnitude of their token variation among the large number of exemplars that were measured. We easily found objects that could be classified into two groups: a group containing objects whose tokens were all about the same size, and a group containing objects whose tokens varied substantially among themselves. This finding concerns a property of the distribution of tokens of object types—an ecological variable. It shows that token variability (Criterion 4) is logically relevant, since objects can be distinguished by the amount of their token variation.

We make no claim as to the proportion of common objects that are in the two classes or to their discontinuity, only that it was easy to find a number of exemplars of both classes.

College students know the prototypic sizes of familiar objects. This is shown by the overall very high R^2 values found from the regression analyses and from the evidence of a ratio scaling of the estimated size judgments. Even without having had an opportunity to examine the objects visually, the subjects made size estimates whose variance was almost entirely accounted for by the true sizes of the objects, producing correlations between estimated and true size approaching unity.

This result also provides evidence that when Criterion 2 (prior exposure) underlying the concept of familiarity is satisfied, Criterion 3 (knowledge of prototypic size) is also satisfied.

Token variation affects the accuracy of size estimations. This conclusion is supported by two results. We found that the accuracy of estimating the prototypic size of an object (as assessed by R^2) is significantly greater for objects with very low token variance. We also found that the variation among the size estimates made by the subjects was significantly lower for objects with low token variance.

The latter finding suggests that when a group of subjects are asked to estimate the size of a familiar object (elicited by its name) whose tokens have been demonstrated to be invariant in size, all of the subjects seem to have the same sized objects in mind when they make their estimates. This produced the lower between-subjects *SD* in the size estimations. In contrast, when estimating the size of an object whose tokens have been demonstrated to be more variable in size, one of two different processes might be occurring. One is that each subject has a somewhat different sized instance of the prototype in mind and produces that value when asked to make an estimate. The other is that all subjects have a less precise sense of the prototypic (average) size of token variable objects, so that there is more variation between subjects. The latter alternative would suggest also more within-subjects variation for the token variable objects if they were asked to repeat this task several times.

Whatever the explanation, the finding is robust: Size estimations are more accurate for token invariant objects than for token variable objects.

Do subjects know that objects differ in token variation? We did not ask the subjects directly to classify these objects into categories on the basis of their estimated token variances. Even so, the data from the regression analyses suggest that the subjects could have performed this task with great accuracy. However, it is possible that the subjects had only a single token of an object in mind when they made their size estimations and that they were not aware that token-to-token variation differed among the objects. If that was the case, since the token variable objects exist in a range of sizes, the single tokens in mind among the subjects would differ among themselves, thereby producing a greater between-subjects variation in estimations. We failed to eliminate this possibility.

Size "perception" or size cognition? Because these results were all obtained in the absence of any concurrent visual experience with the objects, they support the analysis of size "perception" as a cognitive or memorial process. When subjects are familiar with an object, they use that knowledge to estimate its size and can do so with very high accuracy even without seeing any exemplars of the objects. It is difficult to think of Experiment 1 as a perceptual task.

In Experiment 2, we considered how the sizes of unfamiliar objects are estimated.

In summary, the results support extending the concept of familiar size to knowledge of prototypic size and knowledge of token variance. Not only are subjects knowledgeable about both aspects of an object, but furthermore, token variance is shown to affect the accuracy with which prototypic size is known. This implies that even when objects are in view, cognitive size information for token variable objects would be somewhat less useful in estimating object sizes than for token invariant objects (this implication is explicitly tested in Experiment 2 below). Finally, this suggests that token variance should be considered as an integral part of any theory that uses familiar size as a variable.

EXPERIMENT 2

Subjects were asked to view actual instances of the same objects displayed at various distances in a visually rich natural scene. The two independent variables included type of object (15 objects that were familiar token invariant, 15 that were familiar token variable, and 15 that were unfamiliar) and viewing distance (half the objects were placed in a near viewing range from 10 to 150 ft and half in a more distant range from 150 to over 300 ft). The two dependent measures were the subjects' estimated objective sizes and the estimated objective distances of all of the objects.

Method

Subjects. Nine male college students, all volunteers, screened for normal or corrected-to-normal acuity, binocular, and color vision, served as subjects in Experiment 2. None had participated in Experiment 1.

Stimuli. The 45 stimuli to be judged included the 15 token invariant objects and the 15 token variable objects tested in Experiment 1. Elongated objects (e.g., a bike) were displayed with the long axis perpendicular to the subject's line of regard. In addition, 15 objects of unknown size were used. These consisted of flat cardboard cutouts of three geometric shapes (ovals, rectangles, and triangles), each painted in one of seven different colors (orange, blue, black, yellow, green, white, and red), which were matched in size to the heights of the two other object types. Each of the 45 objects was supported vertically by a hidden stand when necessary.

Placement of stimuli. The experiment was conducted on a single large grassy field, approximately 1,000 × 650 ft, which was bounded by trees on three sides. Each set of 15 objects of a similar type was arrayed in a separate quadrant of the field, radiating out from the center of the field, in such a way that the subjects (who stood in the center) could view only the 15 objects of a single type at a time. The fourth quadrant of the field was empty, so that subjects could walk to the center without seeing any of the objects. The scene beyond the perimeter of each quadrant of the field that contained stimuli was similar: irregular grass for about 300 ft beyond the farthest object in the quadrant, terminating in a visual horizon of dense forest.

The objects were randomly assigned to the true viewing distance from the center of the field with the following constraints: About half of them were located between 10 and 150 ft and the remaining half between 150 and 300 ft from the subject; there was no occlusion among objects from the viewing position of the subject, and the visual angle among the set of 15 objects in any one quadrant was less than 30° from the subject's viewing position. The correlation between object height and viewing distance was trivial.

Procedure. The 45 objects were placed on the field prior to the arrival of the subjects. The subjects arrived by van, stood with their backs to the field, and were given complete instructions before they walked onto the field. Then they were told to walk single file with their heads and eyes down. They followed the experimenter, who led them to the center of the field through the fourth quadrant and turned them so that they faced the direction that they had just come from. In this way, the subjects could not see the objects arrayed around them until the testing began.

All 9 subjects were tested at the same time. During the testing, the subjects stood in groups of 3, each group facing toward a different quadrant of the field. Each subject was randomly assigned to begin at one of the three quadrants.

The subjects were given a pen and a clip board, on which was attached a scoring sheet with the names of 15 objects listed in a random order. The names given for the token invariant and token variable objects were chosen so as to be descriptive without conveying additional size information (e.g., *bicycle* not *ten speed bicycle*). The unknown objects were named by color and shape (e.g., *blue triangle*).

Two blank lines followed each of the 15 object names. One column of blank lines was labeled "distance" and the other was labeled "height". The subjects were instructed to estimate the objective distance from themselves to each object and to enter that estimate on the first blank line after the object's name. The estimate of the objective height above the ground of each object at the tallest part of the object was to be entered on the second blank line after the object's name. The subjects were told that they could make the two estimates in either order.

When all 9 subjects had made all 30 estimates (15 heights and 15 distances) of the objects in one quadrant (object type), the experimenter told them which quadrant they were to observe next, and they turned at the same time, repeating the procedure with a new scoring sheet.

After all subjects had estimated all objective distances and objective sizes, they returned to the van area, and, with their backs to the field, they filled out two questionnaires. The first asked the subjects to rate the familiarity of each of the token invariant and token variable objects that they had just viewed on a scale of 1 (not at all familiar) to 10 (highly familiar). The second questionnaire asked for cognitive size estimates of the 30 objects, using the same format as that employed in Experiment 1.

Size Perception Results

Are the "familiar" objects familiar? First, we verified that the objects on the questionnaire in Experiment 1 were also familiar to the new set of subjects. In response to the familiarity questionnaire, the lowest rating given by any subject for any object was 7 (on a 10-point scale). Averaging across subjects, no object had a mean familiarity rating significantly different from 10 (range, 8.1–10, $M = 8.86, p > .10$). Furthermore, the mean familiar rating for the two groups of objects did not differ from each other (8.92 and 8.80, respectively, $p > .10$). Therefore, these 30 objects were highly familiar to the new subjects.

How accurately do subjects estimate object sizes while looking at the objects? Fifty-four regression equations of the form

$$\text{estimated size} = (B) \text{ true size}$$

were calculated to determine the source and amount of variance accounted for in size estimations, one equation for each of the 9 subjects for each of the three object types for each of the two distance ranges. The grand mean (over the 9 subjects, three object types, and two viewing distances) is $R^2 = .95$. Hence, the true size of an object accounted for virtually all of the variance in estimated objective size by the subjects. The results, broken down by object type and viewing distance (discussed below) are displayed in Figure 1.

Does the object's token variability affect size estimation accuracy? The mean R^2 for the three object classes (.97, .94, and .94, respectively, as is shown in Figure 1) were significantly different from one another

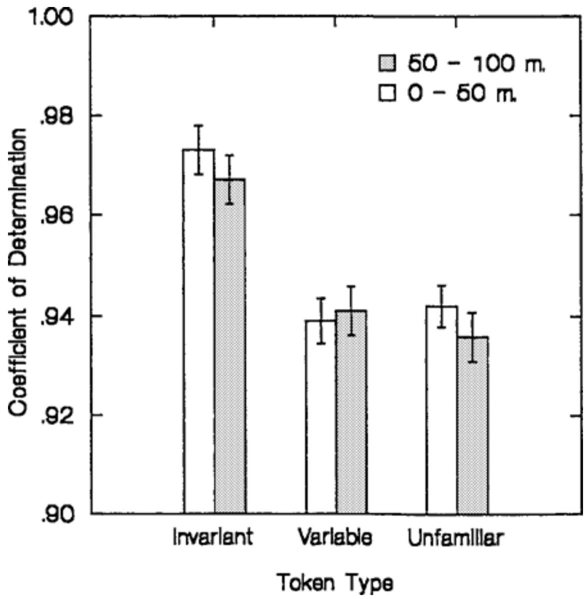

Figure 1. Mean R^2 from regression analyses using true size to predict estimated size as a function of object type and distance range.

[$F(2,16) = 6.59, p < .005$]. Scheffé comparisons indicated that this effect was due to the higher R^2 for the token invariant objects compared with either the token variable objects ($p < .05$) or with unknown objects ($p < .05$), with the latter two not differing between themselves. This result suggests that if the prototypic size is known and token variance is minimal, size estimations are more accurate, as compared with when token variance is larger or prototype size and token variance are unknown.

Does viewing the objects improve the accuracy of estimating their sizes? We compared the 9 subjects in Experiment 2 who looked at the objects with the 109 subjects in Experiment 1 who did the size estimation task entirely from memory. We also compared visually based estimates with the memory-based estimates of the same 9 subjects in Experiment 2, since they made their estimates both ways.

The R^2 values based on the 9 subjects in Experiment 2 under visual conditions (R^2 = .97 and .94, respectively) were not significantly different ($p > .10$) from the comparable ones based on the 109 subjects in Experiment 1 (R^2 = .97 and .92, respectively), in which there were no visual access to the objects.

To determine whether viewed size (estimates made while standing in the field) or remembered size (estimates taken from the questionnaire responses) of the 9 subjects was a better predictor of estimated size, 36 of the above regression equations were recomputed using stepwise combinations of the two predictor terms (the cognitive size term could not be included in the model statement for the unfamiliar objects because those objects have no known remembered sizes). No difference in mean R^2 was found ($p > .10$): Both viewed size and remembered size predictors accounted for the same (high) amount of variance when compared directly or when compared in stepwise additions.

Taken together, these results show that the subjects were equally accurate in making size estimations from memory and from concurrent perception.

Does distance information, true distance, or estimated distance affect size estimations? We used the variable of distance range to manipulate the quality of distance information, since there is overwhelming evidence that objective distances are estimated more accurately for objects in near distance when compared with far distance (see Gillam, 1995; Sedgwick, 1986, for reviews). As can be seen in Figure 1, there was no main effect of range distance on size estimation accuracy ($p > .10$) and no interaction of distance range and object class ($p > .10$). The estimations of object sizes were just as accurate when the objects were far away as when they were near. This result suggests that distance information is not used to improve size estimations.

To determine whether either true distance or estimated distance might predict estimated size, the true distance to each object and the estimated distance to each object were added as additional terms to the regression equations just examined. However, for none of the 54 equations did adding either predictor significantly improve the prediction of estimated size ($p > .10$), nor did they improve predictions for any of the three object classes considered separately.

Thus, considering all 54 size estimation equations or subgroups of them by object class or distance, adding predictors based on adequacy of distance information, true distance, or estimated distance (or signed error in size estimation, or absolute error in size estimation, which we also verified) had no effect on predicting size estimation. In this experiment, no variable involving distance impacted size estimations. This was also the case for the unfamiliar objects.

How accurately are the sizes of unfamiliar objects estimated? Even though there is no remembered size information available for the 15 unfamiliar objects, the subjects were also quite accurate in estimating those sizes, though significantly less so than for token invariant familiar objects. The high mean R^2 for the unfamiliar objects (mean R^2 = .94) surprised us; we had expected it to be much lower than the mean R^2 = .97 for familiar token invariant objects, following the assumption that the lack of remembered size information would impair size estimation accuracy. The significant difference suggests that this lack of information does impair performance, but not by much. This result in isolation shows that subjects can estimate the sizes of even totally unfamiliar objects quite accurately. It also suggests that token variable objects are estimated no better than the totally unfamiliar objects (mean R^2 = .94 in each case). We will return to the implications of these results after considering those for distance estimations.

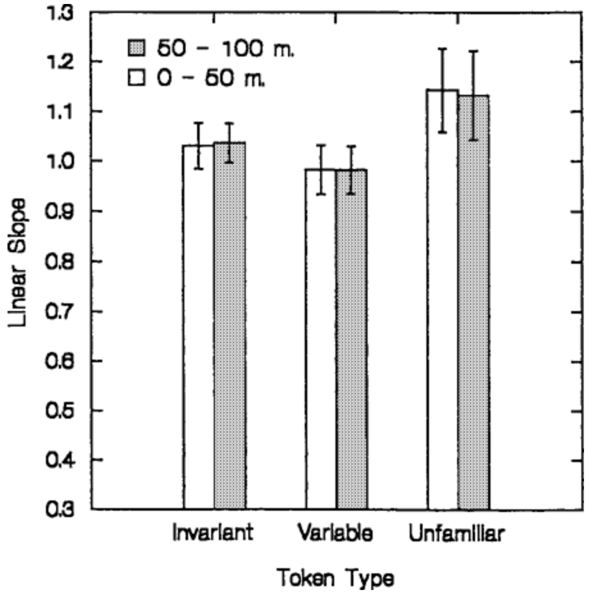

Figure 2. Mean regression coefficients (B) from regression analyses using true size to predict estimated size as a function of object type and distance range.

Scaling properties of visually estimating size. All regression equations were linear (exponents were not different from unity), and all had a true zero point (intercepts were not different from zero). The remaining variable is the regression coefficient or scaling factor (B) from each equation, which, given the zero intercept and unity exponent, provides an estimate of the slope of the linear regression function, or the amount of over- or underestimation of size. The mean coefficient on true size did not differ from unity for any of the three object types (mean B = 1.03, 0.98, and 1.14, respectively, $p > .10$), a finding comparable to that for sizes estimated from memory in Experiment 1. Nor did they interact with distance range. However, the three slopes do differ among themselves [$F(2,16) = 5.77, p < .05$], with Scheffé tests showing that the unknown objects (which were not measured in Experiment 1) were significantly more overestimated in size than were the token variable objects ($p < .05$). These results are displayed in Figure 2.

Distance Perception Results

How accurately can subjects estimate distance from themselves to objects? Fifty-four linear regression equations of the form

$$\text{estimated distance} = (B)\ \text{true distance}$$

were computed, comparable with those already reported for size perception (9 subjects × 3 object types × 2 distance ranges). The mean R^2 averaged over all 54 equations is .97. This shows that true distance accounted for nearly all of the variance in the subjects' estimates of objective distance. The subjects were therefore very accurate.

Is accuracy of distance estimation affected by distance information and by size information? These two questions are considered together because there is an interaction between the independent variables of object distance and object type. Figure 3 shows the results of the 54 equations above broken down by distance range (the manipulation of the quality of distance information) and object class (the manipulation of familiar size information). The apparent interaction is significant [$F(2,48) = 4.44, p < .05$]. Although the two main effects are also significant ($p < .05$), those effects are obviously due to the strength of the interaction.

Planned comparisons revealed that for the near distance range, in which distance information is assumed to be quite good (white bars), change in object type had no effect on the accuracy of the distance estimates ($p > .05$). For the far distance range, in which distance information is assumed to be poorer (dark bars), all three object types differed among themselves: The accuracy of estimating the distances to token invariant objects was significantly higher than to token variable objects ($p < .05$), and those were significantly higher than for unknown objects ($p < .05$). Further, for token invariant objects, distance range had no effect on the accuracy of the distance estimates ($p > .05$). For both token variable objects and unknown objects, the far distance range did show a significant reduction in the accuracy of the distance estimates ($p > .01$).

Summarizing these results, true distance accounts for virtually all of the variance in estimated distance; the amount of variance accounted for was unaffected by the object type when distance information was good; and the amount of variance accounted for by true distance was re-

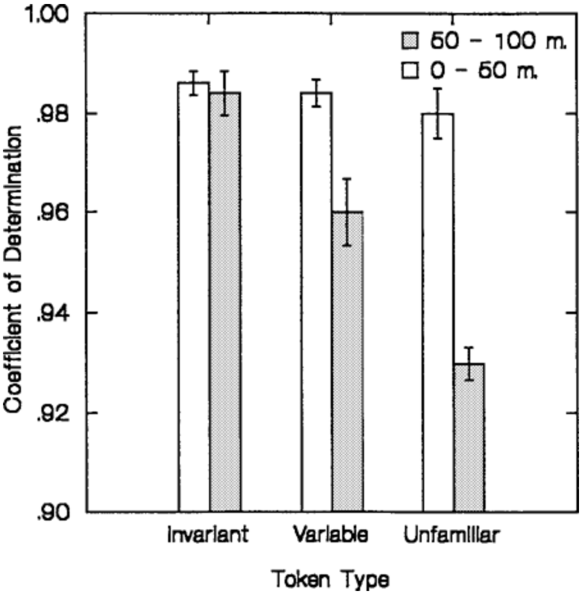

Figure 3. Mean R^2 from regression analyses using true distance to predict estimated distance as a function of object type and distance range.

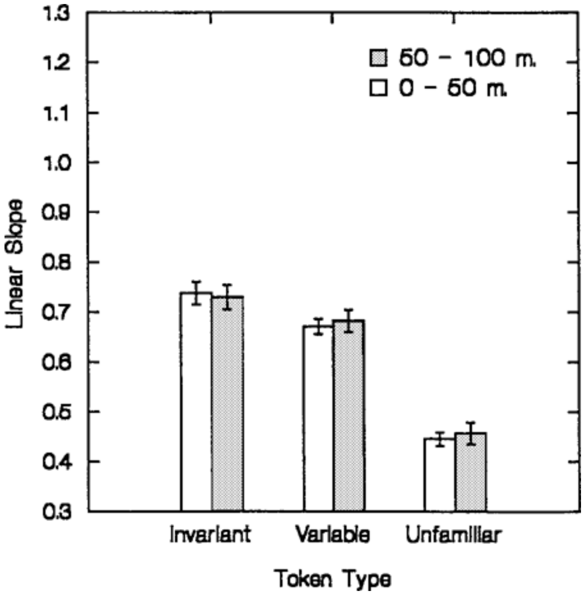

Figure 4. Mean regression coefficient (B) from regression analyses using true distance to predict estimated distance as a function of object type and distance range.

duced when distance information was reduced. However, when distance information was poorer, estimations of distances improved when the objects provided better familiar size information. Thus, size information was used to improve distance estimations when distance information itself was inadequate.

It should be noted that while the R^2 values are very high, they are not at ceiling: As the results indicate, it is still possible to demonstrate significant variation in accuracy as either distance information or size information is degraded.

Scaling properties of visually estimating distance. As with size estimation, the mean intercept (A) is not significantly different from zero, and the mean exponent (C) is not significantly different from unity, so that the function relating true distance to estimated distance is linear with a true zero point. Figure 4 shows the means of the slopes, given by the coefficient (B) of true distance, averaged over all 54 equations. The overall mean was .62 (which was significantly less than unity—$p < .001$), indicating that even though linear, there was a substantial underestimation of distance.

Underestimation of distance was not affected by the quality of distance information. Although previous results (e.g., Sedgwick, 1986) suggest that more underestimation of distance should be found at far than at near distances, an ANOVA failed to replicate this finding: There was no significant difference in the amount of underestimation between the near and the far distance (mean B = 0.61 and 0.63, respectively, $p > .10$).

However, underestimation of distance was affected by object type. An ANOVA revealed that the three object types differed in slope (mean B = 0.734, 0.676, and 0.456, respectively) [$F(2,51) = 9.80$, $p < .001$], with each of these significantly less than unity ($p < .05$). Scheffé tests also showed that the slope for token invariant objects was significantly higher (less underestimation of distance) than was the slope for token variable objects ($p < .05$), with the latter slope significantly higher than that for the unknown objects ($p < .01$).

Therefore, size information effects distance underestimation, with more underestimation occurring as the quality of information specifying object size is reduced.

GENERAL DISCUSSION

Empirical Demonstrations of an Ecological Definition of Familiarity

Several criteria to meet a definition of familiarity were proposed: (1) recognizability, (2) prior experience, (3) knowledge of prototypic size, and (4) knowledge of token variation. The present results provide a start in operationalization of these definitions.

Criterion 1 was not manipulated in the present research, though we were convinced in pretesting that all of these objects could be seen and identified by name or by color and shape even at 300 ft. However, it is still important to verify that observers have adequate perceptual opportunity to identify an object before any effect of its familiarity can become apparent.

To have had prior experience with an object (Criterion 2) so as to be able to recognize or identify it, has usually been the only criterion for familiarity considered in past research. The present results strongly suggest that when this criterion is satisfied, the much more important Criterion 3 is also satisfied: Prior experience imparts knowledge of the prototypic size of the object. From memory alone, without viewing the object, subjects can provide size estimates that are highly accurate using a ratio scale of size.

Criterion 4, knowledge of token variation, introduces a new dimension, which we have manipulated for the first time. The present results strongly indicate the importance of this criterion. Some familiar objects have little token variation and others have a great deal, and these differences in token variation affect the estimates of size and distance made by subjects. The present results indicate that object token size variation and subjects' knowledge of that variation should be measured and manipulated in experiments in which familiarity with the stimuli is important.

Overall Levels of Accuracy of Size and Distance Perception

Because the subjects were always asked to provide objective physical size and distance estimations in the present experiments, their match to true sizes and distances can be assessed. We assumed that physical measurements of true size and true distance follow ratio scales. The subjects in both experiments, both for sizes and distances, produced estimations that were very close to these objective physical dimensions. For size, this was especially true: The scaling of estimated size to true size follows a ratio scale (zero intercept, unity slope and unity power). Physical size ranged from less than a half foot to nearly 6 feet; yet the average absolute error in the subjects' estimates was less than 2 in. Distance estimations were less accurate only in the sense that the subjects underestimated distances systematically; but even so, their estimates were almost perfectly correlated with true distance. Hence, across all conditions, the subjects were able to give highly accurate size and distance estimates.

Our asking the subjects to provide estimates using natural units (e.g., feet and inches) is not a common experimental procedure. The majority of experiments require unit-free estimates (e.g., magnitude estimation), comparison judgments (e.g., which is larger), or nonverbal estimates (e.g., adjustment of a standard), all of which require more complex assumptions in order to allow conclusions about accuracy. We expected that adult subjects could make direct estimations in natural units (the present results strongly support us), and, by requesting responses in natural units, we learned much more about what the subjects knew of the stimuli and the task (for further discussion, see Levin & Haber, 1993; Toye, 1986).

The Role of Prototypic Size Knowledge and Token Variation in the Perception of Size and of Distance

With respect to size estimation, the results of Experiment 2 show that the sizes of token invariant objects were more accurately estimated than were those of token variable familiar objects and totally unfamiliar objects. With respect to distance estimations, the results of Experiment 2 show that the distances to token invariant objects were estimated more accurately than those to token variable or unfamiliar objects, but only for larger distances where distance estimations were less accurate under all conditions. Hence, when information to distance was less than complete, familiarity with object size helped, especially if the object had little token size variation.

For the distance estimation results, we found a three-way difference: Token invariant familiar objects provided more information to distance than did token variable familiar objects, both of which provided more information than unfamiliar objects. This allowed for separation of two effects. First, previous experience, which, by the results of Experiment 1 provided highly accurate information about prototypic size, aided in the estimation of distance, regardless of whether token sizes were highly variable or not. Second, low token variation provided some additional information that could be used to help estimate distances accurately.

The comparable three-way difference was not found for size estimation. Familiarity did not increase the accuracy of size estimations unless the object had size invariant tokens.

Even so, for the perception of both size and distance, the amount of token variation of the familiar objects affected accuracy.

How do Subjects Estimate the Sizes of Token Variable Familiar Objects So Well?

Again, although token variable objects were estimated with less accuracy than were token invariant objects, their accuracy levels were still impressively high. The logic underlying the ecological-based importance of token variation would suggest that size memory for objects with substantial token variation should provide much less help in estimating their sizes accurately. So why did the subjects do so well?

One possible explanation is that some familiar objects with high token variability might contain some familiar subcomponents that are token invariant. For example, Christmas trees have high token variation, even when considering just those for home consumption. However, their needle length and needle diameter is close to token invariant for any given type of pine tree. Hence, by observing the needles, observers have access to some size invariant information, even though the overall height of the tree varies unpredictably. With this token invariant information imbedded in a token variable object, observers may be able to determine the overall size more accurately than they could do otherwise.

What is needed to explore this possibility is a thorough examination of the visual information contained in objects and in scenes that specify object sizes.

Why do Subjects Estimate the Sizes of Unfamiliar Objects so Well?

Although Experiment 2 showed consistently that the subjects estimated the sizes of the unfamiliar objects with less accuracy than those of familiar ones, the analyses also showed that their estimations were still quite accurate. The scaling between true and estimated size still followed a ratio scale (zero intercept, unity power, and with a slope only slightly above unity), and the mean multiple correlation was $R^2 = .94$. The average absolute error between estimated size and true size for the unfamiliar objects, regardless of viewing distance, was only 4 in.

The 15 unfamiliar objects were cardboard cutouts in the shape of squares, rectangles, and ovals. These objects conveyed no overall familiar size information: The relatively accurate size estimates could not have been produced from memory based on prior contact with the objects. So why did the subjects do so well? We consider and reject four possibilities, the first two of which are based on familiarity, the last two on perception.

One could argue that our unfamiliar objects still conveyed some familiarity, based on fortuitous shape–size correlations. But this seems unlikely. They were cut from very large sheets of heavy cardboard into regular geometric shapes of different sizes and were painted with different flat colors. There was no correlation between either the objects' sizes and their construction (shape, color, thickness, or surface texture) or with their placement in the field. Nor could the subjects have seen or interacted with the objects before making their judgments. Even though the subjects could identify the different shapes and colors, they had no way to use that to inform themselves about the objects' sizes.

Following the argument about token variable familiar objects, perhaps these objects contained some token invariant familiar details that could be used to estimate their overall sizes. However, we could neither think of any possibilities nor find any after the fact by examination of the painted cardboards.

While all of the 45 objects are on display in the same grassy field, the objects of different familiarity types are located in different 90° quadrants, with a 30° empty gap between the nearest objects of different familiarity. The subjects had been instructed to face only one quadrant at a time and to not look across to any of the others while responding to one of them. We did not observe any subject doing this. Therefore, it is unlikely that the subjects could have compared the distances to familiar and unfamiliar objects in the same or immediately successive glances, and used the distance information to help them estimate sizes of the unfamiliar objects. Furthermore, because distance information did not predict size estimation accuracy, it does not appear that "peeking" would have helped. Finally, there was no interaction in the accuracy of estimating the sizes of unfamiliar objects as a function of whether the subjects judged the familiar or unfamiliar objects first.

Could there have been any perceptual information available while the subjects looking at the objects that was predictive of their sizes? Several examples can be imagined. If there is a single source of illumination (especially a distant one) lighting a group of objects in a scene (as was the case), the length of an object's shadow cast on the ground will be correlated with the object's height. If observers take the singularity of illumination into account, they will have access to a scalar for each object's size, without having any familiarity with the objects. As a different example, if a number of the objects share similar surface texture (which was the case) and are located close enough to the observer so that the texture density is perceivable (unlikely for the very distant objects), then the extent (or number) of the textural elements will be correlated with the extent of the object itself. Again, if perceivers take the singularity of surface qualities into account, they will have access to a partial scalar for object size.

The problem with the examples of potential sources of perceptual information and all similar ones, is that these are just the kinds of stimulation that are also used for distance perception. Yet, there is no correlation between the accuracy of size estimations and distance estimations. If the subjects were using a source of information for size perception that also underlies distance perception, there should have been a correlation between these distance variables and size estimations. But there is none. These were just the kinds of objects that the *size–distance invariance hypothesis* (SDIH) was designed to describe: When the objects are unfamiliar and their properties are unknown, distance information should help subjects estimate their sizes. Yet, it did not do so.

There is a further problem with a dependence on distance variables to inform size perception. The stimulus information examples just suggested (illumination, object surface texture), plus most others that could be mentioned (e.g., stereopsis, motion perspective), undergo substantial degradation with distance, especially over the distance ranges used here. There is clear evidence of this in the distance estimations: lower accuracy and greater underestimation at the greater distances. But size estimations were not degraded at the farther distances!

We do not know how the subjects arrived at the size estimations for the unfamiliar objects in this experiment. All we can say is that they did not do it in the same way as they did for the distance estimations. This ignorance reflects a general ignorance about the perceptual variables underlying size perception. Most of the theoretical discussions about size perception appeal to familiarity (as do we) and ignore any other variables. But there must be some others, and size perception theorists have to identify and demonstrate them (see Gillam, 1995, for some hints).

The Perception of Object Size is Independent of Object Distance

In Experiment 2, we failed to find any hint that the accuracy of size perception of an object was affected by the true distance to the object, by the amount of distance information in the scene, by the subject's estimated distance to the object, or by the accuracy or error made in distance estimation. The ability to estimate the size of objects located from 10 to 100 ft was unaffected by any variable involving distance.

This conclusion is just as valid for unfamiliar objects (see above) about which the subjects had no prior knowledge of their token or prototypic size, as for highly familiar token invariant objects. Since the unfamiliar objects were estimated less accurately in size than were familiar ones in Experiment 2, the failure of distance to aid size perception cannot be attributed to a ceiling effect.

Although the results regarding the role of distance in the perception of object size may be surprising to those who believe that distance information is used to perceive size, we feel they make good sense. Most of the objects we encounter in the natural world are known objects with invariant or moderately variable tokens. For these object types, the accuracy of the perception of their sizes should be primarily dependent on the accuracy of identification, the degree of familiarity, and knowledge of their token variability. The role of distance cues in aiding the perception of the sizes of known objects may be far less important (as long as the object is close enough to identify or recognize unambiguously).

Size is a property of objects themselves, not of their location, nor of the location of perceivers. Given that we live in a world primarily made up of rigid objects, size is a constant for any specific instance of an object. The instances of objects of a given name (e.g., basketballs) have a prototypic size and a token size variation that are dependent solely on the distribution of such objects. We suggest that our *knowledge* of the world and not our *perception* of the world determines our estimates of the size of objects in the world. Specifically, for most objects, the perception of their sizes is independent of distance perception. Furthermore, the token variability of objects should exert a stronger effect on their size perception than should cues to their distance.

Hence, the formulation of the size–distance invariance hypothesis (SDIH) as

perceived size = distance 3 tangent of retinal size

not only fails to describe the data for any interpretation of distance inserted into the equation but it seems irrelevant for explaining how we interact with objects.

One could argue that had we used a greater range of distances, or impaired distance information in some other way, perhaps we would have found an effect of distance on size perception. But this argument is backwards. Distance information would be expected to be helpful, under the SDIH, when it is very accurate, not when it is inaccurate or degraded. Hence, the impact of distance information should have been found for the objects in the near distance, those seen under ideal conditions.

If the SDIH does not account for size perception, what does? For familiar objects, these experiments provide a clear answer—the estimation of the size of a familiar object is determined primarily from the observer's knowledge of its size acquired from prior experience with the object class and its tokens

perceived size = true (known) size.

This conclusion is strengthened by the findings that the size estimation results obtained in Experiment 1 (without perception) are the same as those in Experiment 2 (with perception). Hence, the component of size "perception" based on familiarity with prototypic size for objects with low token size variation should be more parsimoniously described as a memory, prior knowledge or experience effect, and not perceptual at all.

The Perception of Object Distance is Independent of Object Size

At first blush, the SDIH, which assumes an explicit dependence of distance on size perception (see Epstein, 1961; Kilpatrick & Ittelson, 1953), fared well in the form

perceived distance = true size/tangent of retinal size.

The critical support comes from the finding that when the quality of distance information is reduced (objects located from 150–300 ft, as compared with 10–150 ft) and overall accuracy of distance perception was poorer (validating that distance information was reduced in quality), the loss in accuracy was not found for the familiar objects, especially those with low token size variance. This is just the condition in which the SDIH predicts that familiar size should be effective in aiding distance perception.

However, the above finding is a between-conditions effect, one that depends on the selection of objects. It fails as a within-conditions effect. For example, change true size to perceived size in the SDIH equation so it now reads

perceived distance

= perceived size/tangent of retinal size.

In Experiment 2, we found no support for this form of the SDIH: Neither perceived size nor accuracy in estimating size accounted for any variance in any of the regression equations predicting distance. Hence, even though the token variation status of the objects themselves affected the accuracy of estimating their distance, the perception of their size did not.

This failure would seem to violate the computational implications of the SDIH. It is not clear how subjects use the knowledge gained from prototypic size or from token variance to help them perceive an object's distance, but it is not by substituting into an equation their knowledge of its prototypic size, their knowledge of its token variance, nor their estimate of the object's size while looking at it. Again, it looks as if familiarity is not a perceptual variable.

As with the absence of distance information or distance perception in the prediction of size perception, the absence of size perception in the prediction of distance perception seems reasonable to us. Because human beings are highly mobile organisms, distances always vary. Therefore, the distance to an object must be perceived at the time of observation and cannot be determined by reference to prior experience with distances or to prior experience with the objects whose distances are being perceived. Such logic suggests that the perception of distance is determined heavily by environmental sources of information that describe distance and not by the familiarity of objects or other kinds of knowledge carried by the perceiver.

Therefore, we expect that access to familiar size information about objects in a scene does not provide much assistance in the perception of the distance to such objects and certainly not when there is already good distance information.

The moral is clear. We need to study size perception in the same way that we have studied distance perception for the past 200 years: We need to consider the physiological, visual, environmental, and ecological sources of information that specify object sizes. We have a good understanding of distance perception from this approach. With an equivalent focus, size perception should catch up.

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NOTES

1. In all regression analyses reported in this research, we started with a nonlinear model, one for each subject; for example,

$$\text{cognitive estimated size} = \text{A} + \text{B (true size)}^{\text{C}}$$

and then tested the intercept A against 0.00 and the exponent C against 1.00. In each case, we accepted the null hypothesis of zero and unity, respectively, based on the appropriate statistical tests and dropped these terms. Thus, the final equation was the linear form

$$\text{cognitive size estimate} = \text{B (true size)},$$

one equation for each subject. Furthermore, residual plots for each subject revealed no heteroscedasticity, and for no subject was there a significant correlation between the absolute residual and the predictor.

2. It is possible to model equations that predict, for each object, the error in its estimated size, defined as the difference between the estimated size judgment made by the subject and the mean measured prototypic size of the object, as reported in column 1 of Table 1. Modeling the error in estimation is mathematically equivalent to modeling the estimation directly. Therefore, we interpret the magnitude of the R^2 as a measure of accuracy: The greater the amount of variance accounted for in predicting estimated size by true size, the greater the subject's accuracy in estimating size. Furthermore, we used three measures of size estimation as dependent variables in the regression analyses: estimated size, absolute error in size (true size minus estimated size), and signed error in size. Since these are so highly correlated, analyses are reported only for estimated size. The other two produce the same pattern of findings. Therefore, when results are described in terms of accuracy, the same conclusions apply to descriptions of error.

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