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The effects of size, clutter, and complexity on vanishing-point distances in visual imagery

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Summary. The portrayal of vanishing-point distances in visual imagery was examined in six experiments. In all experiments, subjects formed visual images of squares, and the squares were to be oriented orthogonally to subjects' line of sight. The squares differed in their level of surface complexity, and were either undivided, divided into 4 equally sized smaller squares, or divided into 16 equally sized smaller squares. Squares also differed in stated referent size, and ranged from 3 in. to 128 ft along each side. After subjects had formed an image of a specified square, they transformed their image so that the square was portrayed to move away from them. Eventually, the imaged square was portrayed to be so far away that if it were any further away, it could not be identified. Subjects estimated the distance to the square that was portrayed in their image at that time, the vanishing-point distance, and the relationship between stated referent size and imaged vanishing-point distance was best described by a power function with an exponent less than 1. In general, there were trends for exponents (slopes on log axes) to increase slightly and for multiplicative constants (y intercepts on log axes) to decrease as surface complexity increased. No differences in exponents or in multiplicative constants were found when the vanishing-point was approached from either subthreshold or suprathreshold directions. When clutter in the form of additional imaged objects located to either side of the primary imaged object was added to the image, the exponent of the vanishing-point function increased slightly and the multiplicative constant decreased. The success of a power function (and the failure of the size-distance invariance hypothesis) in describing the vanishing-point distance function calls into question the notions (a) that a constant grain size exists in the imaginal visual field at a given location and (b) that grain size specifies a lower limit in the storage of information in visual images.

Introduction

Structural properties of visual images have been a topic of interest for several years (for review, see Finke, 1989; Kosslyn, 1980; Shepard & Cooper, 1982). One of the prime structural properties is metric space and the question of whether such space is preserved in images has been cause for lengthy debate (e.g., see Kosslyn, 1981; Pylyshyn, 1981). One aspect of metric space has involved the notion of *minimum resolution* and the question of whether images possess a minimum resolution. This issue is often couched in terms of the *grain* of the image, where grain is analogous to the minimum resolution in a photograph or to the size of pixels on a CRT screen. Some theorists have proposed that the grain of the image may change across the surface of the image (paralleling the lessening of acuity from fovea to periphery on the retina, e.g., Finke & Kosslyn, 1980, Finke & Kurtzman, 1981; but see also Intons-Peterson & White, 1981). Implicit in this idea is that the grain size at any given point in the image remains constant, just as the grain size at any given point in the visual field remains constant. Another aspect of this problem involves the specification of object size and distance. Studies that examine the effects of the relative size of imaged objects have been in circulation for years now (e.g., Kosslyn, 1975), but studies of the portrayed distance of imaged objects are more recent.

Three types of characteristic distances in imagery have been examined: overflow, first-sight, and vanishing-point. The initial work was done by Kosslyn (1978, 1980), who reported a series of experiments measuring the *overflow* distance in images – that is, the imaged distance at which the subjective size of an imaged object becomes too large to be seen all at once (i.e., in a single glance of the "mind's eye").[1] Overflow distance was typically obtained by

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[1] It should be stressed that the phrases "imaged distance" and "imaging the object moving" do not refer to instructing subjects to project their images outside of their heads. Instead, these phrases refer to the distance portrayed within a visual image and transformations within a visual image.

having the subject image an object and then transform the image by "mentally walking" toward the object in the image. Overflow distance conformed to the size-distance invariance hypothesis (SDIH; for reviews of SDIH see Baird, 1970; Epstein, Park & Casey, 1961; Sedgwick, 1986)

$$\tan \theta = S/D \tag{1 a}$$

or equivalently

$$D = (1/\tan \theta)S \tag{1 b}$$

where S represents the stated size of the referent object, D represents the distance portrayed in the image, and θ represents the visual angle resulting from the relationship between size and distance. Kosslyn (1978, 1980) found a linear relationship between the stated physical size of the object and the minimum distance (maximum angular size) portrayed in an image of that object. This linear relationship defined the maximum "visual angle of the mind's eye," and while such a visual angle was constant for a particular class of objects, it differed greatly between different classes of objects.

The second type of distance examined was *first-sight* distance, the distance at which an imaged object is initially portrayed in an untransformed image. Hubbard, Kall, and Baird (1989; Hubbard & Baird, 1988) found a nonlinear relationship between the stated size of an object and the distance at which that object was initially imaged, a relationship best described by a power function with an exponent less than 1:

$$D = \lambda S^{\gamma} \tag{2}$$

where γ represents the curvature of the function and λ is a scaling factor dependent upon the units of measurement (notice that Equations 1 a and 1 b are special cases of Equation 2 [in which $\gamma = 1$]). First-sight distance, while determined partly by the metric size of the referent object, was also affected by the type of object. In general, smaller objects were imaged at closer distances than larger objects, but smaller objects that were typically experienced at farther distances (e. g., a bird's nest) were imaged at farther distances, while larger objects typically experienced at nearer distances (e. g., a refrigerator) were imaged at nearer distances. As a result, the first-sight functions were more variable than the overflow functions.

A third type of distance examined was *vanishing-point* distance, the distance at which an imaged object is portrayed at so great a distance from the observer that it is barely discernible. If, in fact, the notion of grain is correct and the grain size at a given point in the image is constant, then we should obtain a constant minimum resolution (a minimum visual angle of the mind's eye), and imaged vanishing-point distance should be linearly related to the stated object size. The logic is as follows. Grain size corresponds to the minimum subjective size of the object, and subjects' knowledge of the stated size of a physical exemplar of the type of object they image allows them to estimate the distance (using the SDIH) that the object would have to be in order to appear the minimum subjective size. Since size and distance in the SDIH are linearly related (see Equations 1 a and 1 b), the relationship between object (grain) size and vanishing-point must also be linear. Hubbard and Baird (1988), however, reported that the function relating stated size to imaged vanishing-point distance was not linear, but was instead a power function with an exponent (γ) of approximately 0.7. Similar functions were found when descriptions of both familiar objects and featureless rods were used as stimuli, suggesting that this function was due to properties of the imagery system and not to the properties of the particular stimuli. It is not immediately clear how to reconcile these results with the predictions made from the SDIH and structural theories of imagery.

We report a series of experiments that examine vanishing-point distance in imagery in greater detail. Several questions are examined. (a) What is the relationship between first-sight and vanishing-point estimates? Both functions are described by similar exponents; one possibility is that vanishing-point estimates may simply be some multiple of first-sight estimates. Because previous work has collected first-sight and vanishing-point estimates from separate groups of subjects, the relationship between the two types of distances cannot be interpreted as clearly as if both types of estimate had been collected from the same subjects. (b) What is the role of surface detail in reported imaged vanishing-point distance? For overflow, surface detail is thought to be less important than length along the longest axis (Kosslyn, 1978), but it is not clear that a similar relationship holds for vanishing-point. For example, considerations of acuity suggest that less detailed objects might be recognizable at greater distances. (c) Could the vanishing-point functions reported earlier result from errors of anticipation or habituation inherent in the psychophysical methods employed? (d) Can the distance portrayed in an image be influenced by the content of the image? Previous investigation into the effects of clutter (e. g., intervening objects such as buildings, railroad tracks, or cities) in cognitive maps have shown that the presence of clutter leads to larger estimates of distances than are obtained when clutter is not present (e. g., Thorndyke, 1981). Could the presence of clutter in a visual image influence the function that relates imaged vanishing-point distance to object size?

Experiment 1

In this experiment subjects give estimates of both first-sight and vanishing-point imaged distances for 30 objects of various stated sizes and levels of detail. The effect of surface detail is not easy to predict, but there are three obvious possibilities: (a) surface detail may not have any effect on the imaged vanishing-point distance; (b) surface detail may increase the imaged vanishing-point distance; (c) surface detail may decrease the imaged vanishing-point distance. This third possibility is the more intuitive one, because acuity may demand that a surface with fine details becomes indiscernible at a much closer distance than a surface that is relatively featureless.

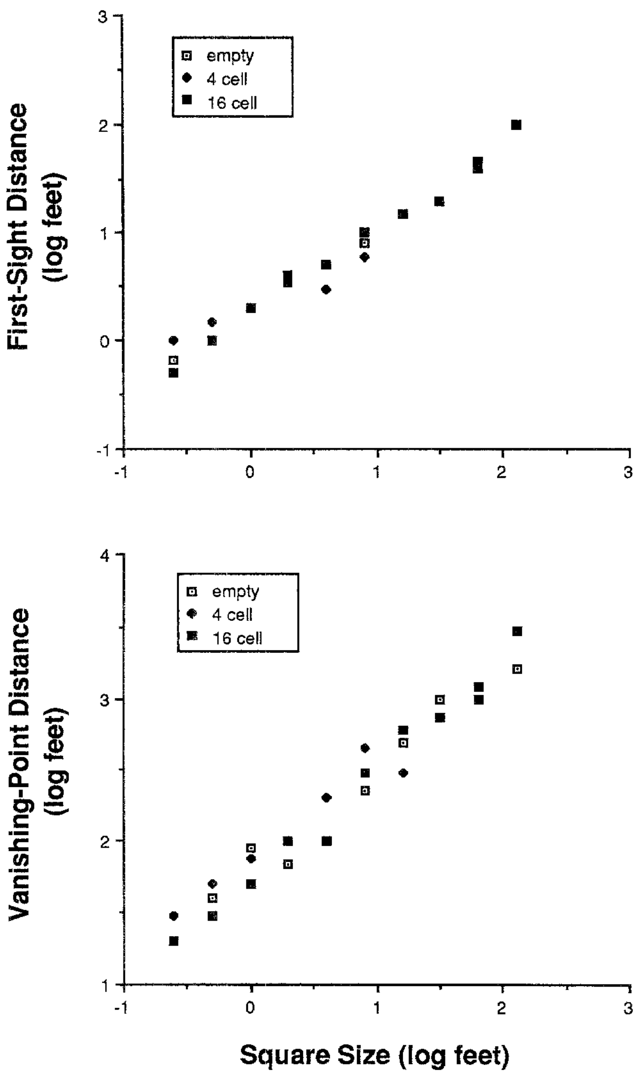

Fig. 1. Median distance judgments as a function of object size in Experiment 1. Data for the first-sight estimates are displayed in the top panel and data for the vanishing-point estimates are displayed in the bottom panel

Method

Subjects. The subjects were 21 Dartmouth College undergraduates who were recruited from introductory psychology classes. All subjects were naive to the hypotheses and received extra credit in an introductory psychology class in return for participation.

Stimuli. The stimuli were descriptions of squares that varied along two dimensions: complexity (i. e., surface detail) and size. Each square was divided into either 0, 4, or 16 equal-sized cells and was described as either an empty, 4-cell, or 16-cell square. The outer sides of the squares were described as being either 0.25, 0.5, 1, 2, 4, 8, 16, 32, 64, or 128 ft in length. The design crossed complexity and size, yielding a total of 30 stimuli (3 complexities × 10 sizes). The descriptions were assembled into a six-page booklet. The first page of the booklet gave sample drawings of each type of square (empty, 4-cell, and 16-cell), and the second page gave detailed instructions. The third through fifth pages each contained four columns, with the complexity and size of each stimulus listed in the two left-hand columns and blanks for subjects' estimates in the two right-hand columns. The stimuli were listed in a different random order for each subject. On the sixth page a series of questions asked the subjects if they had used any particular strategies during the experiment and what they thought the predictions and purposes of the experiment were.

Procedure. Subjects were run in groups of four or five, but worked individually. Each subject was given a booklet. Subjects read the size and complexity of the first square, then were instructed to form a visual image (a mental picture) of what a square of that size and complexity would look like. They were asked to make their image of the square as vivid as possible. They then estimated the distance to the square that was portrayed in their image and wrote that distance in the first blank next to the description of the square (*first-sight* distance). Subjects then re-formed their image and were asked to imagine that the square moved away from them. Eventually, there would come a time when the square had moved so far away that they could just barely see it and still identify it. They then estimated that distance and wrote it in the second blank next to the description of the square (*vanishing-point* distance). The instructions emphasized that at the vanishing-point subjects should still be able to "see" that the imaged object was a square (as opposed to merely an unidentifiable shape) and that they should also still be able to "see" the surface detail (i. e., identify whether the square was empty, 4-cell, or 16-cell). Such strict criteria for vanishing-point were used in order to help insure that subjects were truly discriminating the information on their images (in which case the details would need to be larger than the grain) and not merely detecting whether or not some stimulus was present in their images (in which case the details could be smaller than the grain). Subjects repeated this procedure for all subsequent squares. They were allowed as much time as they needed to complete the experiment, but all were finished within 30 min.

Results

Taking the logarithm of each side of Equation 2, we obtain

$$\log D = \gamma \log S + \log \lambda \qquad (3)$$

in which the exponent γ in Equation 2 is now the slope in Equation 3, and is easily determined by calculating the slope of the best-fitting line via least-squares regression. Accordingly, the logarithm of the median distance judgment for each of the stimuli was computed for both first-sight and vanishing-point conditions, and these medians were plotted against the logarithm of the stated size of the stimuli. The first-sight data are shown in the top panel of Figure 1 and the vanishing-point data are shown in the bottom panel.

For both first-sight and vanishing-point, the slope of the best-fitting line was taken as an estimate of γ and the y intercept was taken as an estimate of log λ. The power function offers a valid description of the relationship between object size and both first-sight and vanishing-point distances (all r^2s >.96). For first-sight, least-squares regression yields a log λ of 0.27 and a γ of 0.76 for the empty square, a log λ of 0.31 and a γ of 0.70 for the 4-cell square, and a log λ of 0.24 and a γ of 0.79 for the 16-cell square. These first-sight functions are less variable than those found previously when descriptions of more familiar objects were used as stimuli, supporting our earlier suggestion that familiarity with typical distances influences first-sight distance. The artificial squares used in the current experiments would not have had familiar distances associated with them, and so might thus offer a purer (or at least a less variable) indication of the influence of object size on imaged distance. For vanishing-point, least-squares regression yields a log λ of 1.76 and a γ of 0.71 for the empty square, a log λ of 1.87 and a γ of 0.68 for the 4-cell

Table 1. Exponents (γ) and y intercepts (λ) in Experiments 1–6

Experiment		Surface Detail					
		Empty		4-cell		16-cell	
		γ	log λ	γ	log λ	γ	log λ
1	first sight	0.77	0.27	0.76	0.26	0.76	0.29
	vanishing-point	0.69	1.82	0.72	1.80	0.78	1.72
2	vanishing-point	0.76	1.85	0.80	1.77	0.81	1.72
3	predicted vanishing-point	0.72	1.69	0.72	1.62	0.71	1.52
	calculated vanishing-point	0.79	1.82	0.76	1.84	0.80	1.79
4	clutter vanishing-point	0.71	2.18	0.71	2.19	0.73	2.19
	clear vanishing-point	0.68	1.95	0.65	1.82	0.68	1.70
5	clutter first-sight	0.52	0.59	0.50	0.57	0.52	0.55
	clear first-sight	0.43	0.62	0.45	0.65	0.43	0.61
	clutter vanishing-point	0.63	2.04	0.63	2.03	0.71	1.94
	clear vanishing-point	0.64	2.03	0.62	2.05	0.63	2.06
6	asymmetric partial clutter vanishing-point	0.70	1.98	0.69	1.92	0.71	1.85
	symmetric partial clutter vanishing-point	0.71	2.11	0.72	2.08	0.72	2.03

square, and a log λ of 1.72 and a γ of 0.79 for the 16-cell square.

Equation 3 was also used to calculate individual functions for each subject for each distance type (first-sight, vanishing-point) and complexity level (empty, 4-cell, 16-cell). These estimates of subjects' slopes and intercepts were analyzed in separate 2 (Distance Type) $\times$ 3 (Complexity) ANOVAs, and the mean exponents and multiplicative constants for each of the distance type and complexity levels are listed in Table 1. A linear-model description of both first-sight and vanishing-point distances can be rejected because all of the exponents are well below the γ of 1 predicted by a linear model. First-sight and vanishing-point exponents did not differ, $F(1,20) = .85$, $p = .37$, nor did Complexity influence the exponents, $F(2,40) = 1.35$, $p = .27$, or y intercepts, $F(2,40) = 1.01$, $p = .37$. The interaction of Distance Type and Complexity was marginally significant for exponents, $F(2,40) = 3.13$, $p = .055$, and as is shown in the top panel of Figure 1, this appears to be due to more complex images demonstrating larger vanishing-point exponents than less complex images. First-sight y intercepts are significantly smaller than vanishing-point y intercepts, $F(1,20) = 146.40$, $p < .0001$, as would be expected, since first-sight distance is smaller than vanishing-point distance. The interaction of Distance Type and Complexity was marginally significant for y intercepts, $F(2,40) = 3.04$, $p = .059$, and as is shown in the bottom panel of Figure 1, this appears to be due to more complex images demonstrating smaller vanishing-point y intercepts than less complex images.

Given the relative similarity between the first-sight and vanishing-point exponents, it is possible that subjects may have merely taken their estimate of first-sight distance, multiplied it by some constant, and used that value as an estimate of vanishing-point distance. Examination of the ratio of vanishing-point to first-sight estimates argues against this possibility, as no consistent pattern is found. The VP:FS ratio ranges from under 2 to over 4,500. Furthermore, the Pearson product-moment correlation between the two measures is only .5, suggesting that only a quarter of the variance in the vanishing-point distance can be accounted for by consideration of first-sight distance. In any case, the data for both first-sight and vanishing-point exponents are inconsistent with the SDIH (Equations 1 a and 1 b) because all exponents are less than 1.

Discussion

For first-sight distances, there is no tendency for either the slope or the y intercept either to increase or to decrease with changes in complexity. For vanishing-point, however, the slope seems to increase and the y intercept seems to decrease as complexity increases. This interaction, albeit marginally significant in both slope and y-intercept analyses, is consistent with the claim that subjects' answers are based on actual inspection of images. For first-sight images, there is no reason to suppose that more complex objects need be imaged at closer distances, but for vanishing-point images, acuity may demand that more complex objects (i.e., surfaces with finer details) become indiscernible at closer distances than objects of the same size that are relatively featureless.

Experiment 2

In Experiment 1, subjects gave a first-sight judgment before making their vanishing-point judgment; they therefore gave the smaller first-sight distance before giving the larger vanishing-point distance. This pattern may have inadvertently biased their judgments because the vanishing-point threshold was always approached from the same direction, that is, by increasing the distance. A parallel may be drawn from classical psychophysics. In the Method of Limits, subjects are presented with a sequence of stimuli in

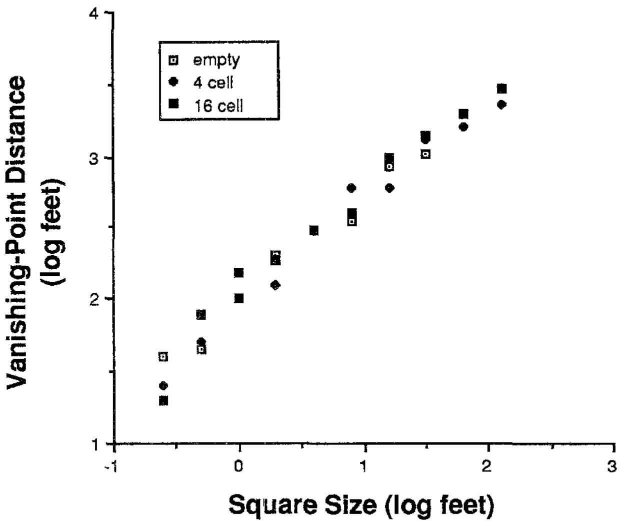

Fig. 2. Median vanishing-point distance as a function of object size in Experiment 2

which the intensity is gradually increased or gradually decreased. After each stimulus presentation, subjects report if a stimulus was perceived. If the stimulus intensity begins at a subthreshold level and gradually increases, subjects may nonetheless continue to report "NO" after the stimulus intensity has reached suprathreshold levels, thus making the threshold appear to be higher than it really is (an error of habituation). Conversely, subjects may anticipate the arrival of the stimulus at threshold and prematurely report perception of the stimulus (an error of anticipation). One technique for limiting errors of anticipation or habituation is to vary the starting point of stimulus intensity; therefore, in Experiment 2, the starting point is moved from typical first-sight distance (closer than vanishing-point) to a point so far away that subjects cannot yet see it in their images (further than vanishing-point). If vanishing-point distance in Experiment 1 was systematically affected by the starting point, by errors of either anticipation or habituation, then different functions should be obtained in Experiment 2 because a different starting point is used.

Method

Subjects. The subjects were 19 Dartmouth College undergraduates drawn from the same pool as in Experiment 1, and none of the subjects had participated in Experiment 1.

Stimuli. The stimuli were the same as in Experiment 1, with the following exception: the instructions were modified so that subjects approached the vanishing-point threshold from the subthreshold (distance greater than vanishing-point) direction.

Procedure. The procedure was the same as in Experiment 1, except that the instructions were modified as follows. Subjects were told to form a visual image of a wide-open plain. They were told that the square was on the plain in front of them, but it was too far away to be seen in their image. Subjects were then to imagine moving along the plain in the direction of where they knew the square to be. Eventually, after they had moved far enough, the square would become visible as a small, barely discernible figure off in the distance. They were to estimate this distance and write it in the blank next to the description of the square. As in Experiment 1, a strict criterion of vanishing-point was used such that at the vanishing-point subjects should still be able to identify the identity and complexity level of the stimulus.

Results

The median distance estimates were analyzed as in Experiment 1 and are displayed in Figure 2. The power function offers a valid description of the relationship between stated object size and vanishing-point distance (all r^2s >.96). Least-squares regression yields a log λ of 2.02 and a γ of 0.70 for the empty square, a log λ of 1.97 and a γ of 0.71 for the 4-cell square, and a log λ of 1.98 and a γ of 0.76 for the 16-cell square. Both the log λ and the γ values are remarkably close to the log λ and γ values for vanishing-point obtained in Experiment 1. As in Experiment 1, there is a trend for more detailed targets to yield higher exponents than less detailed targets.

Individual functions for each subject for each complexity (empty, 4-cell, 16-cell) were calculated as in Experiment 1 and analyzed in an ANOVA, and the mean exponents and multiplicative constants for each complexity level are listed in Table 1. Complexity did not influence the exponents, $F(2,36) = 1.29, p = .29$, although, as in Experiment 1, there is a weak trend for more complex objects to have slightly higher vanishing-point exponents. Consistent with the trend seen in Experiment 1, there was a marginally significant effect of complexity on the y intercepts, $F(2,36) = 2.87, p = .07$, such that more complex objects exhibited lower y intercepts.

When sample size was increased by the combination of the vanishing-point data of Experiment 2 with the vanishing-point data from Experiment 1, more complex objects had significantly higher vanishing-point exponents, $F(2,76) = 4.74, p = .012$ and significantly lower y intercepts, $F(2,76) = 5.33, p = .007$. Direction of Approach to the vanishing-point boundary did not affect the exponent, $F(1,38) = .81, p = .38$, or the y intercept, $F(1,38) = 0.0, p = .99$, nor were the Direction of Approach $\times$ Complexity interactions for the exponent, $F(2,76) = .87, p = .42$, or the y intercept, $F(2,76) = .46, p = .63$, significant. Failure to find an effect of Direction or an interaction of Direction $\times$ Complexity does not support the hypothesis of a systematic error of habituation or anticipation.

Discussion

Overall, complexity of the imaged object influences the vanishing-point function in such a way that more complex objects exhibit a lower y intercept and a slightly higher slope. It should be noted that the slope and the y intercept are normally not independent; a linear function that pivots at any point other than $x = 0$ will necessarily create an inverse relationship between the slope and the y intercept (e.g., see Harver, Tenney, & Baird, 1986). The observed pattern is consistent with the notion that surface detail contributes to the vanishing-point distance of an imaged object. Thus, vanishing-point distance in an image is not

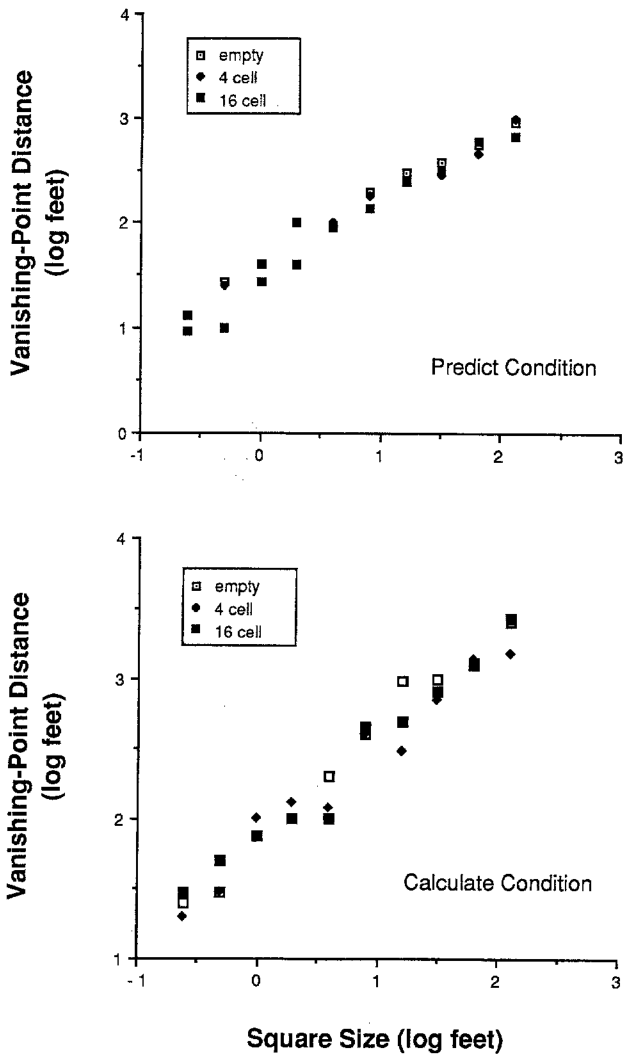

Fig. 3. Median distance judgments as a function of object size in Experiment 3. Data for the predict condition are displayed in the top panel and data for the calculate are displayed in the bottom panel

specified solely by metric properties such as size on the longest axis and distance. Additionally, the vanishing-point slopes and y intercepts obtained in Experiment 2 are similar to those obtained in Experiment 1 (see Table 1), suggesting that errors of anticipation or habituation do not systematically affect either γ or λ.

Experiment 3

It is possible that the results in Experiments 1 and 2 were not due to properties of imagery per se, but to some other nonimaginal factor. For example, subjects may possess tacit knowledge of the SDIH. If this is true, subjects may simply calculate what they believe to be appropriate vanishing-point values for the different stimuli. In Experiment 3 naive subjects who are not explicitly told to image the stimuli are asked to estimate the distance at which actual physical squares of the stated size would vanish. One group of subjects is asked merely to predict the distance, and a second group of subjects is asked explicitly to calculate the distance. If subjects have an intuitive conception of the SDIH, a linear function should obtain. If a power function with an exponent of approximately 0.7 is found, this will not necessarily invalidate an explanation based on properties of imagery (especially if these subjects report resorting to imagery), but if some other type of function or other value of the exponent is found, then this would offer evidence that the functions observed earlier were due to properties of imagery, and not other, nonimaginal strategies.

Method

Subjects. The subjects were 51 undergraduates from Eastern Oregon State College who were recruited from introductory and intermediate psychology classes. Twenty-four subjects participated in a *predict* condition and twenty-seven participated in a *calculate* condition. All were naive to the hypotheses and received extra credit in an introductory psychology class in return for participation.

Stimuli. The stimuli were the same as in Experiment 1 with the following exceptions: first, only vanishing-point estimates were collected; second, two versions of the stimulus booklet were produced, a *predict* version and a *calculate* version. The instructions were modified so that no mention was made of the use of imagery or visualization for either the predict condition or the calculate condition, and for the calculate condition subjects were also told explicitly to calculate the distance.

Procedure. Experimenters naive to the hypotheses were employed in order to reduce the possibility of demand characteristics. The procedure was the same as in Experiment 1 except that the instructions were modified as follows. In the predict condition subjects were asked to estimate the distance (in feet) at which an object of the stated size and detail would be so far away that it would be just barely identifiable – that is, the distance at which if the object were any further away, it could not be identified. No strategy or suggestion concerning how to make the prediction was given. In the calculate condition subjects were asked to calculate the distance (in feet) at which an object of the stated size and detail would be so far away that it would be just barely identifiable – that is, the distance at which, if the object were any further away, it could not be identified. No formulae or other suggestions concerning how to make the calculation were given. As in Experiment 1, a strict criterion of vanishing-point was used.

Results

Inspection of the answers to questions about subjects' strategies revealed that 22 out of the 24 subjects in the predict condition and 24 of out 27 subjects in the calculate condition reported relying on visualization at least part of the time, so our attempt to remove imagery from the experiment was not successful.

The logarithms of the median distance estimates for each of the squares are shown in Figure 3, with data from the predict condition plotted in the top panel and data from the calculate condition plotted in the bottom panel. The power function offers a valid description of the relationship between object size and vanishing-point distance for both the predict and calculate conditions (all r^2s >.98). For the predict condition, least-squares regression yields log λs of 1.63, 1.61, and 1.40 and γs of 0.65, 0.64, and 0.75 for the empty square, 4-cell square, 16-cell square, respectively. For the calculate data, least-squares regression yields a log

λs of 1.83, 1.80, and 1.85 and γs of 0.77, 0.69, and 0.71 for the empty square, 4-cell square, and 16-cell square, respectively.

Individual functions for each subject for each type of instruction (predict, calculate) and complexity (empty, 4-cell, 16-cell) were calculated as in Experiment 1 and analyzed in separate 2 (Instruction) $\times$ 3 (Complexity) ANOVAs, and the mean exponents and multiplicative constants for each of the instruction and complexity levels are listed in Table 1. Instructions did not significantly influence the exponent, $F(1,49) = .76$, $p = .39$, although the trend is for subjects told to use calculation ($\gamma = 0.78$) to have slightly higher exponents than subjects told to merely predict ($\gamma = 0.72$). This trend is consistent with the idea that if subjects calculate, they may merely be taking the distance for a close object and then multiplying out the distance for a large object. Such a strategy would lead to a more linear function ($\gamma = 1$), and indeed, the exponent for subjects told to calculate is slightly closer to 1. Instructions did not significantly influence the y intercept, $F(1,49) = 1.15$, $p = .29$, although there is a trend for subjects told to calculate ($\lambda = 1.82$) to have slightly higher y intercepts than subjects told to merely predict ($\lambda = 1.61$). Complexity did not affect the exponent, $F(2,98) = .76$, $p = .29$, but there was a marginally significant trend for more complex objects to exhibit smaller y intercepts, $F(2,98) = 2.66$, $p = .075$. The Instructions $\times$ Complexity interaction was not significant for either exponents, $F(2,98) = .41$, $p = .67$, or y intercepts, $F(2,98) = 1.50$, $p = .23$.

Discussion

The trend of increasing exponent with increasing complexity observed in Experiments 1 and 2 is largely absent in the data from Experiment 3, suggesting that perhaps this pattern is due more to properties of imagery (and imagistic portrayal) than to any pure calculation or intuitive understanding of the SDIH. However, the trend of decreasing y intercept observed previously is present in the data of Experiment 3. It is possible, then, that this pattern might be explained without an appeal to any properties of imagistic portrayal. However, this pattern in the y intercepts is much more pronounced in the data of the prediction group. The prediction subjects were not given any strategy and may have relied to a larger extent on imagery in making their estimations than did subjects in the calculate group.

Experiment 4

Up to this point we have ignored the surrounding context in which the object is embedded within the image. It is possible, however, that such context may influence distance estimates; for example, a filled space is often judged to be longer or larger than an unfilled space of the same objective size (e.g., Coren & Ward, 1979; Luria, Kinney, & Weisman, 1967; Pressey, 1974). A consistent finding in the cognitive mapping literature is that if there is a greater amount of clutter between two locations, then the estimates of distance are generally larger than when there is no clutter. For example, Thorndyke (1981) had subjects learn an artificial map in which cities were either 100, 200, 300, or 400 miles apart and were separated by 0, 1, 2, or 3 intervening cities. When subjects estimated the distances between different pairs of cities, Thorndyke found that (a) the presence of intervening cities led to greater estimates of distance than when no cities intervened and (b) the presence of clutter was associated with a lowering of the psychophysical exponent. Thorndyke suggested that a lower exponent was found in the clutter conditions because an intervening point along a judged route would add approximately the same value to the estimated length, and this would be true, regardless of the length of the route. Therefore, clutter would produce a larger percentage increase in estimates of short distances than in estimates of long distances, thus reducing the exponent. Furthermore, this interaction between the number of intervening points and the length of the judged route would be exaggerated as clutter increased.

In Experiments 1 and 2, the content, or clutter of the imaged scene, apart from the imaged square, was not systematically manipulated.[2] Experiment 4 addresses the possible contribution of clutter by comparing vanishing-point distance estimates from subjects who form cluttered images with vanishing-point estimates from subjects who form uncluttered (or clear) images. Since clutter obviously cannot be interposed directly between the observer and the vanishing-point (as this would obscure the vanishing-point), instead, the imaginal visual field on either side of the imaged squares is filled with hypothetical clutter. If clutter influences the estimation of vanishing-point distance in the same way that it influences the estimation of distance in cognitive maps, then we should see lower exponents in the clutter condition. Although Thorndyke (1981) did not explicitly report y intercept values, examination of Figure 5 in his paper suggests that increased clutter should result in a larger y intercept.

Method

Subjects. The subjects were 46 Eastern Oregon State College undergraduates drawn from the same pool as in Experiment 3. None of the subjects had participated in Experiment 3. There were 23 subjects in the *clutter* group and 23 in the *clear* group.

[2] In Experiment 1, no context was specified, but in Experiment 2, a context of a "wide-open plain" was specified. The "wide-open plain" was mentioned so that subjects could have something in their image before they reached the vanishing-point (otherwise, subjects had difficulty understanding the task), and the "wide-open plain" was chosen as a context that should have influenced imaged distance as little as possible. Even so, the plain might provide a little more context for the imaged squares than was provided in Experiment 1. Although the difference between vanishing-point exponents in Experiments 1 and 2 is not significant, there is a trend for the exponents in Experiment 2 to be slightly larger. This trend is easily understood in light of Experiments 4–6 if we think of the wide open plain as clutter. Thus, Experiment 2 had slightly more clutter than Experiment 1, and hence a slightly higher exponent.

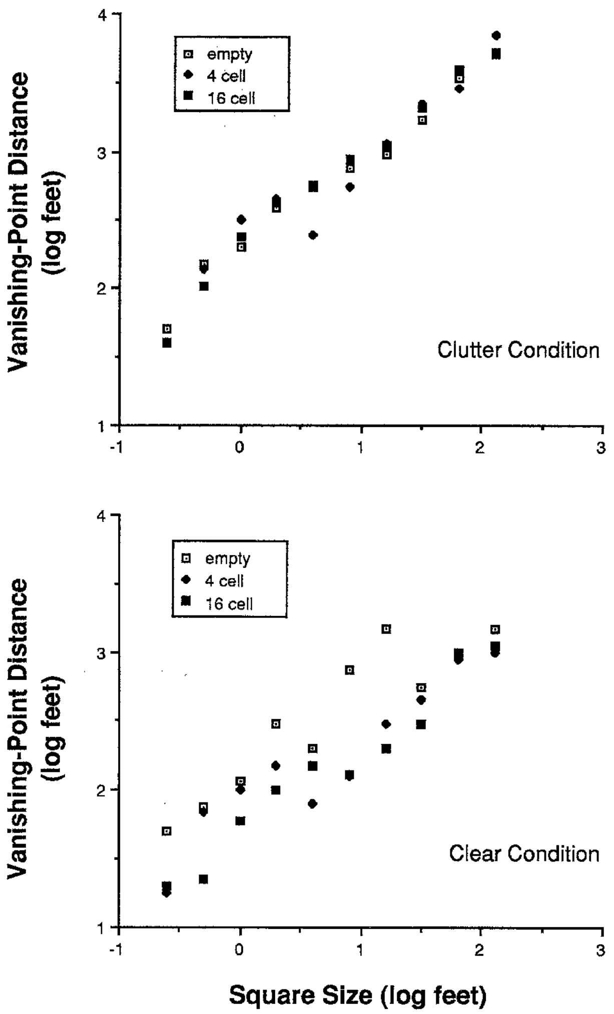

Fig. 4. Median vanishing-point distance as a function of object size in Experiment 4. Data from the clutter condition are displayed in the top panel and data from the clear condition are displayed in the bottom panel

Stimuli. The stimuli were the same as in Experiment 1, with the following exceptions: first, only vanishing-point estimates were collected; second, two versions of the stimulus booklet were produced, a clutter version and a clear version: the clutter instructions stressed that subjects should image the square surrounded by a rich and varied context, whereas the clear instructions stressed that subjects should image the square surrounded by a barren and empty context.

Procedure. Experimenters naive to the hypotheses were employed in order to reduce the possibility of demand characteristics. The procedure was the same as in Experiment 1, except that the instructions were modified to create two different sets of instructions: clutter and clear. Subjects in the clutter group were instructed to image that they were standing between the rails of a railroad track and that the square was placed atop a railroad flatcar directly in front of them. The square was to be placed on the flatcar so that its surface was perpendicular to the subjects' line of sight. The sides of the railroad track, stretching from where the subject stood out to the horizon, were to be lined with buildings, loading docks, warehouses, and other structures (for large squares, these structures might be hidden behind the square initially, but would be revealed as the square receded into the distance). Subjects then imaged that the square and the flatcar upon which it was riding moved down the track away from where they were standing. Eventually the square would reach a point at which it was just barely identifiable (subjects were asked to ignore whether or not the flatcar itself was visible). Subjects then estimated the distance portrayed in their image and wrote that distance in the blank next to the description of the square. As in Experiment 1, a strict criterion for the vanishing-point was used. The instructions for subjects in the clear group were identical to those in the clutter group, except that instead of imaging loading docks, warehouses, and other structures beside the tracks, subjects in the clear group imaged a wide-open empty plain on both sides of the tracks. Although the railroad track and flatcar might be considered to be clutter, these elements were included in both clutter and clear conditions, and so any differences between clutter and clear exponents should be due to the presence of the additional clutter in the clutter group (buildings, warehouses, etc.).

Results

The logarithms of the median distance estimates are displayed in Figure 4, with data from the clutter condition plotted in the top panel (all r^2s >.96) and data from the clear condition plotted in the bottom panel (all r^2s >.88). For the clutter condition, least-squares regression yields log λs of 2.28, 2.24, and 2.25, and γs of 0.68, 0.71, and 0.73 for the empty square, 4-cell square, and 16-cell square, respectively. For the clear condition, least-squares regression yields log λs of 2.13, 1.82, 1.68, and γs of 0.55, 0.56, and 0.64 for the empty square, the 4-cell square, and the 16-cell square, respectively. Clutter appears to have raised both log λ and γ, and consistent with Experiments 1 and 2, we again see a trend for more detailed objects to exhibit larger exponents.

Individual functions for each subject for each context (clutter, clear) and complexity (empty, 4-cell, 16-cell) were calculated as in Experiment 1 and analyzed in separate 2 (Context) $\times$ 3 (Complexity) ANOVAs, and the mean exponents and multiplicative constants for each of the distance type and complexity levels are listed in Table 1. Clutter did not significantly influence the vanishing-point exponent, $F(1,44) = .43$, $p = .52$, although there was a trend for clutter subjects ($\gamma = 0.72$) to have slightly larger exponents than clear subjects ($\gamma = 0.67$). Clutter images produced significantly larger y intercepts than did clear images, $F(1,44) = 4.15$, $p = .05$; this pattern is in the predicted direction, and is perfectly consistent with the idea that distances that are more cluttered or filled (or alternatively, that a distance within an image that is portrayed as being cluttered or filled) are judged to be greater than distances that are uncluttered or unfilled. Neither Complexity, $F(2,88) = .60$, $p = .55$, nor the Complexity $\times$ Context interaction, $F(2,88) = .171$, $p = .84$, influenced exponents. Consistently with previous experiments, more complex images lead to smaller y intercepts, $F(2,88) = 5.58$, $p = .005$, although the effect of complexity is seen most strongly in clear conditions and is practically absent in clutter conditions, $F(2,88) = 6.712$, $p = .002$.

Discussion

It is somewhat surprising that exponents in the clutter condition are slightly higher, albeit nonsignificantly, than exponents in the clear condition, a result opposite to that found in Thorndyke (1981). Why might there be an increase in the exponent rather than a decrease? One possibility involves the percent of the visual field involved in the judgment. Presumably for Thorndyke's subjects, images of the map (or at least of the cities involved in any given judgement) were both within the central areas of the image (either because the map was imaged small enough that the subject could image both cities simultaneously or because the subject sequentially scanned from the first city to the second). It is probable that only rarely did subjects image the map so that one city was at one extreme edge of the image and the second city at the other extreme edge. Thus, in most cases the percentage of the visual field involved in the judgement would be less than 100%. In Experiment 4, however, subjects judged a much greater extent of their possible imaginal visual field, an extent ranging from their viewpoint out to the maximum possible distance from their viewpoint. It is possible that the greater extent involved in Experiment 4 contributed to the differences in exponents between Thorndyke's experiment and Experiment 4.

Experiment 5

One way to determine if the extent of the visual field is critical to the behavior of the exponent is to compare first-sight estimates in both clutter and clear conditions, because the extent of first-sight distance is generally less than the extent of vanishing-point distance for any given object. If first-sight clutter exponents are lower than first-sight clear exponents, this would be consistent with Thorndyke's data and suggest that the pattern found for vanishing-point might be accounted for by the extent of the imaged distance. If, however, first-sight clutter exponents are higher than first-sight clear exponents, this would suggest that the pattern found with vanishing-point exponents need not be due to the greater extent.

Method

Subjects. The subjects were 42 Eastern Oregon State College undergraduates drawn from the same pool as in Experiment 3. None of the subjects had participated in the previous experiments. There were 22 subjects participating in a clutter group and 20 in a clear group.

Stimuli. The stimuli were the same as in Experiment 4, with the following exception: the instructions were modified so that subjects gave distance estimates before and after transforming their images to vanishing-point.

Procedure. The procedure was the same as in Experiment 4, with the following exception: subjects estimated the distance to the square initially portrayed in their image (before transforming their image to vanishing-point), as well as the distance portrayed in their image after the images had been transformed.

Results

When the first-sight distance estimates were examined, an unexpected pattern emerged. Six subjects (three in the clutter condition and three in the clear condition) listed the same first-sight distance for all of the squares. The explanation given by these subjects was that the flatcar, when initially imaged, was always at the same distance (and hence always occupied the same visual angle). After the flatcar was imaged, they would place a square of the appropriate size and surface detail on the flatcar. Thus, the size of the flatcar (which stayed constant), rather than the size of the square, determined first-sight distance. The estimates of these subjects were not included in any further analyses.

The logarithms of the median estimates for the clutter condition are displayed in Figure 5 and the logarithms of the median estimates for the clear condition are displayed in Figure 6; in Figures 5 and 6 the first-sight data are plotted in the top panels and the vanishing-point data in the bottom panels. For first-sight distances (all r^2s >.96), least-squares regression of the clutter data yields log λs of 0.56, 0.55, and 0.58 and γs of 0.53, 0.55, and 0.49 for the empty, the 4-cell, and the 16-cell conditions, respectively. These exponents are slightly lower than those obtained in Experiment 1, but are similar to other previously reported values (Hubbard et al., 1989). The slight decline from the values found in Experiment 1 may be due to the increased cognitive demands in the current experiment, as subjects imaged not only a single object, but an object surrounded by a rich context. For vanishing-point distances (all r^2s >.90), least-squares regression of the clutter data yields log λs of 2.02, 2.03, and 1.85 and γs of 0.63, 0.60, and 0.69 for the empty, 4-cell, and 16-cell conditions, respectively. These exponents are similar to those obtained in Experiment 4. For first-sight distances (all r^2s >.90), least-squares regression of the clear data yields log λs of 0.59, 0.58, and 0.61 and γs of 0.40, 0.40, and 0.41 for the empty, the 4-cell, and the 16-cell conditions, respectively. These exponents are slightly lower than those obtained in the first-sight clutter condition, a result contrary to predictions based on Thorndyke (1981), but consistent with the data from Experiment 4. For vanishing-point distances (all r^2s >.77), least-squares regression of the clear data yields log λs of 2.07, 2.06, and 2.11 and γs of 0.57, 0.56, and 0.63 for the empty, the 4-cell, and the 16-cell conditions, respectively, although the fit of the functions is not as good as that found previously.

Individual functions for each subject for each distance type (first-sight, vanishing-point), context (clutter, clear), and complexity (empty, 4-cell, 16-cell) were calculated as in Experiment 1 and analyzed in separate 2 (Distance type) × 2 (Context) × 3 (Complexity) ANOVAs, and the mean exponents and multiplicative constants for each of the distance type, context, and complexity levels are listed in Table 1. First-sight exponents were significantly less than the vanishing-point exponents, $F(1,43) = 10.88$, $p < .01$, and first-sight y intercepts were significantly less than the vanishing-point y intercepts, $F(1,34) = 172.54$, $p < .001$. Context did not significantly influence the vanishing-point exponent, $F(1,34) = 1.09$, $p = .30$, or the vanishing-point y intercept, $F(1,34) = 1.10$, $p = .74$, although there is once again a trend for clutter ($\gamma = 0.58$) to possess a larger exponent than clear ($\gamma = 0.53$). No other main effects or interactions were significant, all Fs <1.9, all ps >.15.

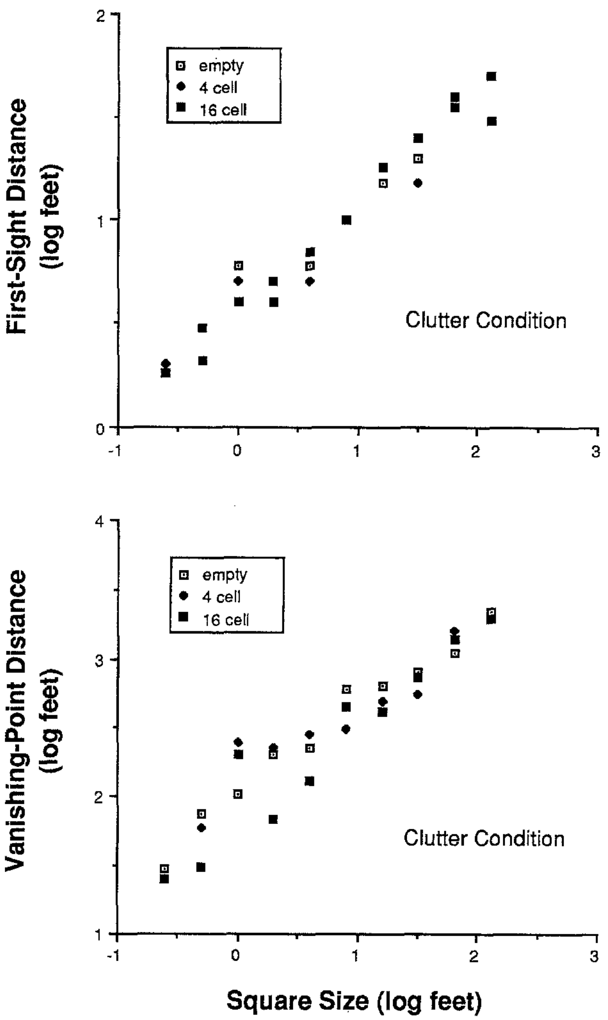

Fig. 5. Median distance judgments as a function of object size in the clutter conditions in Experiment 5. Data for the first-sight estimates are displayed in the top panel and data for the vanishing-point estimates are displayed in the bottom panel

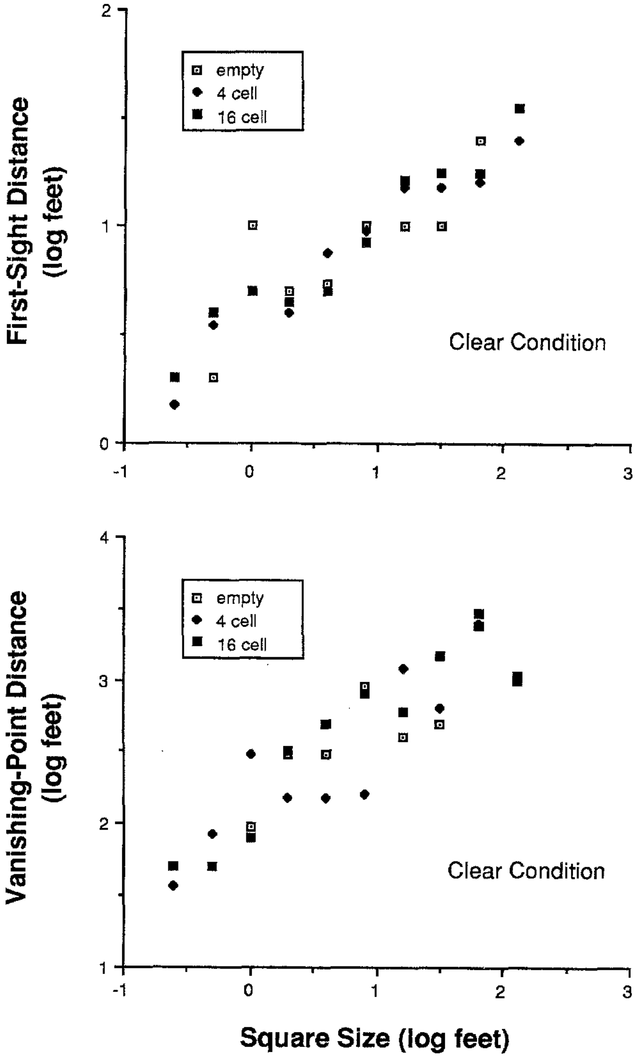

Fig. 6. Median distance judgments as a function of object size in the clear conditions in Experiment 5. Data for the first-sight estimates are displayed in the top panel and data for the vanishing-point estimates are displayed in the bottom panel

Discussion

One unexpected finding is the suggestion that first-sight distance may be primarily determined by which of the objects in the scene is imaged first. When six of the subjects imaged the flatcar first and then imaged the square on top of the flatcar, they gave the same first-sight distance for each square. In contrast, when subjects imaged the square first and then imaged the surrounding context (including the flatcar), first-sight distance was a function of square size. Thus, the first-sight distance of the objects in an imaged scene may be determined primarily by which element of the scene is imaged first.

Consistent with the data of Experiment 4, the vanishing-point exponents in Experiment 5 are also slightly larger in the clutter condition than in the clear condition. However, consistent effects of clutter on log λ were not found. As can be seen in Table 1, the exponents for the first-sight clutter condition are also consistently larger than the exponents for first-sight clear condition at each level of complexity, a pattern consistent with the idea that the pattern of exponents in Experiment 4 cannot be accounted for solely by a consideration of the magnitude of the extent of the visual field to be judged. Nonetheless, it should be stressed that Experiment 5 replicates the direction of the clutter effect found in Experiment 4, strengthening confidence in the finding. However, the differences between clutter and clear y intercepts in Experiment 5 are not as marked as in Experiment 4, nor do we see a consistent effect of complexity on the y intercept. One possible explanation is that Experiment 5 involved more cognitive effort, as the subjects were required to determine both first-sight and vanishing-point distances. Because of the additional cognitive effort required, subjects' estimates may have been moderated; the finding that the values for both clutter and clear y intercepts found in Experiment 5 seem to be intermediate to the values found in Experiment 4 is consistent with this.

Another possible explanation for the different effects of clutter in Thorndyke (1981) and in Experiments 4 and 5

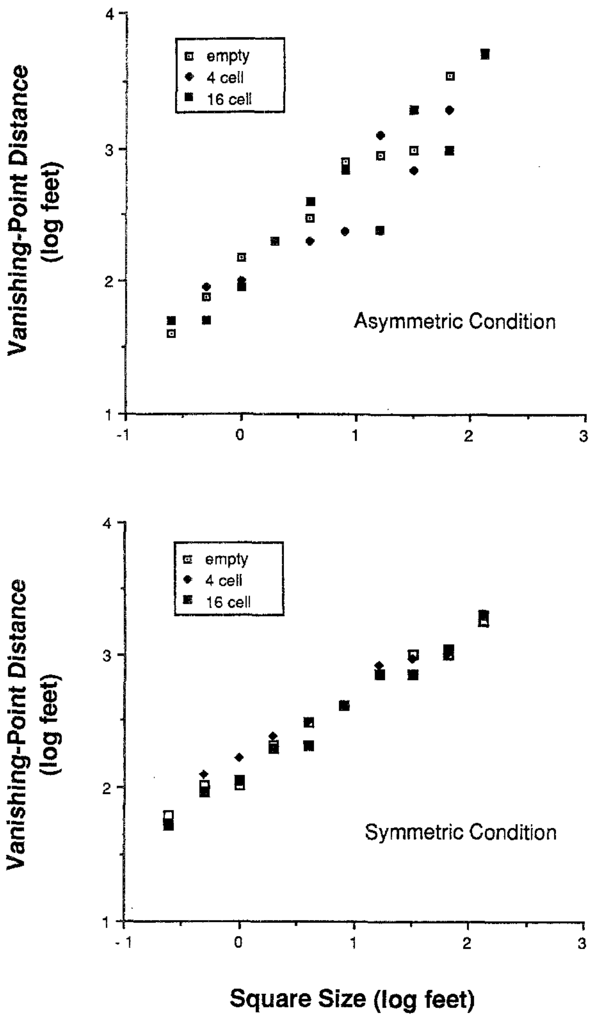

Fig. 7. Median asymmetric partial clutter and median symmetric partial clutter vanishing-point distance as a function of object size in Experiment 6. Data from the asymmetric partial-clutter condition are displayed in the top panel and data from the symmetric partial-clutter condition are displayed in the bottom panel

involves the spacing of the clutter in the different experiments. In the Thorndyke experiments, clutter was not distributed uniformly; that is, clutter consisted of, at most, three intervening points which were separated by large clutter-free areas. In Experiment 4, however, clutter was distributed much more uniformly. Rather than just having 1, 2, or 3 points, each of which was surrounded by relatively large uncluttered space, the instructions in Experiment 4 specified a more uniform distribution of clutter, as the flatcar and railroad track were lined by numerous buildings, warehouses, docks, and so forth along the entire length of the railroad track from the observer to the vanishing-point. If a point of clutter adds the same absolute amount to a distance estimate, and the uniform distribution of clutter in Experiment 4 produces an approximate one-to-one correspondence between a unit of distance and a unit of clutter, then we would expect the imaged distance to be larger in the clutter condition than in the clear condition because every unit of distance in the clutter condition is slightly larger than the equivalent unit of distance in the clear condition. Uniformity of clutter would thus also decrease the relatively larger contributions of the single elements of clutter that Thorndyke (1981) hypothesized to underlie his data.

Experiment 6

It is possible that differences in the uniformity of clutter can account for the differences between Thorndyke's (1981) data and the data of Experiments 4 and 5; specifically, the decreased exponent for clutter in Thorndyke's data resulted from the limited number of widely spaced elements of clutter, while the increased exponent for clutter in Experiments 4 and 5 resulted from the more uniform density of the elements of clutter. One way to determine whether the uniformity of clutter is critical is to compare exponents in a partial-clutter condition with the exponents found in the clutter and clear conditions of Experiment 4. In a partial-clutter condition, subjects image the same wide-open plain as in the clear condition, but add just two separated elements of clutter to their images. If partial-clutter exponents are similar to clear exponents, this would be consistent with Thorndyke's (1981) data and suggest that the pattern found for vanishing-point is due to the uniformity of clutter. If, however, partial-clutter exponents are similar to the clutter exponents, this would suggest that the pattern found for the vanishing-point exponents need not be due to the distribution of clutter.

Method

Subjects. The subjects were 42 Eastern Oregon State College undergraduates drawn from the same pool as in Experiment 3. None of the subjects had participated in the previous experiments. There were 21 subjects in a *symmetric partial clutter* condition and 21 in an *asymmetric partial clutter* condition.

Stimuli. The stimuli were the same as in Experiment 4, with the following exceptions: subjects in the asymmetric partial-clutter condition were instructed to form images that contained a little river underneath the railroad track, and a little railroad station beside the track. Subjects in the symmetric partial-clutter condition were instructed to form images that contained a small cluster of four buildings, two on each side of the railroad track. For both asymmetric and symmetric partial-clutter conditions, the objects were to be imaged at a location approximately halfway between the observer's starting point and the horizon.

Procedure. The procedure was the same as in Experiment 4, with the following exceptions: subjects in the symmetric partial-clutter condition imaged the wide-open plain on both sides of the track, but were told that approximately halfway between where they stood and the horizon was a small cluster of buildings; there were two buildings on each side of the railroad track, and the buildings looked like large warehouses or storage buildings; subjects in the asymmetric partial-clutter condition imaged the wide-open plain on both sides of the track, but were told that ahead of them in the distance, the railroad track crossed over a small creek, and that slightly beyond the creek was a little railroad station beside the track.

Results

The logarithms of the median vanishing-point estimates are displayed in Figure 7, with the asymmetric-clutter data plotted in the top panel and the symmetric-clutter data plotted in the bottom panel. The power function offers a valid description of the relationship between object size and vanishing-point distance for both asymmetric clutter (all r^2s >.90) and symmetric clutter (all r^2s >.98) conditions. For the asymmetric-clutter condition, least-squares regression yields log λs of 2.09, 2.04, and 2.03 and γs of 0.74, 0.69, and 0.69 for the empty square, the 4-cell square, and the 16-cell square, respectively; for the symmetric-clutter condition, least-squares regression yields log λs of 2.11, 2.16, and 2.07 and γs of 0.54, 0.53, and 0.56 for the empty square, the 4-cell square, and the 16-cell square, respectively.

Individual functions for each subject for each context (symmetric partial clutter, asymmetric partial clutter) and complexity (empty, 4-cell, 16-cell) were calculated as in Experiment 1 and analyzed in separate 2 (Context) × 3 (Complexity) ANOVAs, and the mean exponents and multiplicative constants for each of the distance type and complexity conditions are listed in Table 1. Context did not influence the exponents, $F(1,40) = .098, p = .76$, or y intercepts, $F(1,40) = 0.72, p = .40$. Complexity did not significantly affect exponents, $F(2,80) = .35, p = .71$, but more complex figures exhibited smaller y intercepts, $F(2,80) = 6.05, p = .004$. The Context × Complexity interactions were not significant for either exponents, $F(2,80) = .21, p = .81$, or y intercepts, $F(2,80) = .47, p = .63$.

When the partial-clutter data from Experiment 6 are combined with the clear and clutter vanishing-point data from Experiment 4, the effects of context do not reach significance for either exponents, $F(3,84) = .25, p = .86$, or y intercepts, $F(3,84) = 1.57, p = .20$. But for both exponents and y intercepts the trends are in the predicted directions: the symmetric partial-clutter exponent is intermediate between clutter and clear exponents (although the asymmetric partial-clutter exponent is equal to the clutter exponent) and the asymmetric and symmetric partial-clutter y intercepts are intermediate between the clutter and clear y intercepts. Complexity does not affect the exponent, $F(2,168) = .85, p = .43$, but more complex objects do exhibit smaller y intercepts, $F(2,168) = 11.28, p < .001$. No other main effects or interactions were significant, all Fs <.36, all ps >.70.

Discussion

The mean exponents for the partial-clutter conditions are more like the clutter exponents than the clear exponents of Experiment 4. There may be at least two possible reasons for this pattern: (a) perhaps clutter acts in a threshold manner, and that once the critical threshold is surpassed, additional clutter has no influence on the exponent; (b) with cases of extreme clutter, the cognitive demands are too high and so the image or estimation process breaks down, resulting in a plateau (or perhaps even the lower and middle portions of a curvilinear relationship) between clutter and the psychophysical exponent. The relationship between clutter and y intercept was clearer, as both symmetric and asymmetric partial-clutter conditions exhibited y intercepts intermediate to the y intercepts measured in the clutter and clear conditions in Experiment 4.

General discussion

Consistent with earlier findings, the imaged vanishing-point is related to the stated physical size by a power function with an exponent of approximately 0.7 (see Table 1). The failure of the SDIH (Equations 1 a and 1 b) to describe adequately imaged vanishing-point distance calls into question the validity of models of visual imagery that either claim or tacitly assume a constant grain size at a given location in the imaginal visual field. The surface detail on an object can also influence imaged vanishing-point distance when the context is unspecified. In general, as complexity increases, exponents increase slightly and y intercepts decrease. But the effect of complexity is not as strong when context is explicitly manipulated (e. g., clutter introduced), consistent with the notion that complexity is a subtle factor, which may be canceled out or overwhelmed by extra contextual information. The addition of clutter to the image would often also, but not always, result in a trend for larger exponents and larger y intercepts, a pattern consistent with the finding that a filled or a cluttered space is often judged to be larger than an empty or an uncluttered space. There also appears to be no difference in vanishing-point exponents or y intercepts as a function of direction of approach to the vanishing-point threshold.

Although subjects may certainly have been forming images as they were instructed to do (and as they afterward claimed to have done), it might be objected that the information on vanishing-point distance might not have been simply extracted or read off the images in any simple way. More specifically, the distances that subjects reported may have been derived from some combination of dimly remembered past visual experience and some naive notions concerning vision. But even if such top-down penetration of the image occurred, this would not necessarily invalidate any role for the image or demonstrate that the image cannot play a causal role. In fact, the vast majority of subjects reported consulting images and trying to read distance off their images, a finding that hardly suggests that images are unnecessary, useless, or merely epiphenomenal.

The consistent finding of a power function with an exponent less than 1 for imaged vanishing-point distance suggests that the grain at any given point in the image is not constant in size, or at least that grain size may not be a critical parameter of information storage in visual images. One alternative explanation, that the value of the exponent for imaged vanishing-point results from the act of estimating remembered distance (rather than the more specific imaged vanishing-point), can be rejected: in a review of over 70 studies Weist and Bell (1985) showed that remembered distance is related to physical distance by an average exponent of approximately 0.9. While this value is slightly less than 1, it is still clearly larger than the exponents for imaged vanishing-point distance. The relative failure of the SDIH to describe imaged vanishing-point suggests instead that the distance-estimation process utilized in imagery does not result in linear mappings between portrayed distance and physical distance, at least over the range of distances associated with imaged vanishing-point. This notion, however, violates the claims of Kosslyn (1980; Kosslyn, Ball, & Reiser, 1978) that images preserve metric space.[3] Given that the r^2 values for each of the functions were substantial, however, a consistent mapping of some sort was evident. Precisely why the form of this mapping varied from that predicted by the SDIH remains open.

There are several possible ways of accounting for the nonlinear imaged vanishing-point function without sacrificing the notion of constant grain size. The first possibility is that even though the imaged vanishing-point may obey the SDIH, the effects of surface detail, clutter, and so forth, add up to produce deviation from the ideal linear relationship. In this case, the grain size may represent an ideal resolution level that can probably never be attained. It is unclear, however, why such a mechanism would consistently result in a power function with an exponent less than 1 rather than the linear function predicted by the SDIH (perhaps with a lower slope). Such an idea also suggests that perhaps resolution is not as critical a factor for information storage in images as has been previously suggested (e. g., Kosslyn, 1975).

A second possibility is that even though imaged vanishing-point may obey the SDIH, subjects' uncertainty about the distance portrayed in their images could lead to a nonlinear power function by decreasing the response range. This would be consistent with a regression-to-the-mean approach such that small objects would be imaged as larger (and hence further) and large objects would be imaged as smaller (and hence nearer) than their true values. This is difficult to rule out entirely because no independent way of measuring image size has yet been developed, but it is unclear why decreasing the response range should result in a power function with an exponent less than 1 rather than a power function with an exponent equal to 1 (a linear function [with perhaps a different slope on linear axes]) or perhaps even some other type of function.

A third possibility is that even though the imaged vanishing-point may obey the SDIH, the imaged vanishing-point distance yields an exponent less than 1 because the range of distances reported for the imaged vanishing-point is very large. This would agree with suggestions by Poulton (1968) and Teghtsoonian (1971; 1973; see also Teghtsoonian & Teghtsoonian, 1970, 1978) that larger stimulus ranges (i. e., greater ratios between weakest and strongest stimuli) are associated with smaller exponents (when magnitude estimation is used). However, Da Silva (1985) reported an exponent of 0.87 for perceived distance in which the stimulus range was 2.17 log cycles and Hubbard et al. (1989) reported a linear function ($\gamma = 1$) for perceived distance, in which the stimulus range was nearly 3 log cycles. These exponents for perceived distance over stimulus ranges similar to those used to measure the imaged vanishing-point are substantially larger than exponents of the imaged vanishing-point, supporting the notion that while the range of the imaged vanishing-point values may contribute to the value of the exponent, the range cannot totally account for this value. A related possibility is that even though the stimulus range of imaged vanishing-point distances does not determine the exponent, perhaps the absolute magnitude of the vanishing-point distances does. In these experiments, the magnitudes of the vanishing-point distances are very large; it is possible that the large magnitude of distances (rather than the ratio of nearest to farthest) may account in part for the exponent being less than 1.

It appears that the notion of grain size in visual images, as it pertains to the portrayal of information in visual images, has to undergo substantial revision. Since the relationship between stated object size and reported imaged vanishing-point distance is nonlinear, there is no clear evidence for either a constant minimum resolution or a constant grain size at a given location in the imaginal visual field. Instead, resolution of an imaged object seems to be based in part on factors other than object size, such as the surface detail on the imaged object and of the surrounding context (clutter) in the image.

[3] The notion of images preserving metric space might be rescued, however, if all images had to do was preserve the relationships between *perceived* spaced and *imaged* space, and not the relationships between *physical* space and *imaged* spaced (e.g., see Pomerantz & Kubovy's (1981) discussion of "psychophysical complementarity").

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