Perceiving the size of trees: Biological form and the horizon ratio

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Physical constraints produce variations in the shapes of biological objects that correspond to their sizes. Bingham (in press-b) showed that two properties of tree form could be used to evaluate the height of trees. Observers judged simulated tree silhouettes of constant image size appearing on a ground texture gradient with a horizon. According to the horizon ratio hypothesis, the horizon can be used to judge object size because it intersects the image of an object at eye height. The present study was an investigation of whether the locus of the horizon might account for Bingham's previous results. Tree images were projected to a simulated eye height that was twice that used previously. Judgments were not halved, as predicted by the horizon ratio hypothesis. Next, the original results were replicated in viewing conditions that encouraged the use of the horizon ratio by including correct eye height, gaze level, and visual angles. The heights of cylinders were inaccurately judged when they appeared with horizon but without trees. Judgments were much more accurate when the cylinders also appeared in the context of trees.

The forms of biological objects distort with changes in size to preserve the functional relation among physical constraints that scale in different ways with different geometric properties. This has been called the *principle of similitude* (Szücs, 1980; Thompson, 1961). The best-known example is that described by Galileo. The weight to be supported by a bone scales with its volume or the cube of the linear dimension, and the strength of the bone scales with the cross-sectional area or the square of the linear dimension. To preserve the capability for self-support, the bone must grow faster in diameter than in length, with the result that larger bones are proportionately thicker. Although this particular analysis has been revised in more recent studies (McMahon, 1984; Schmidt-Nielsen, 1984; Wainwright, Biggs, Currey, & Gosline, 1976), the principles of the analysis remain. A wide variety of forms and functions in both plants and animals has been studied from this perspective (Calder, 1984; Hildebrand, Bramble, Liem, & Wake, 1985; McMahon & Bonner, 1983; Niklas, 1992; Peters, 1983).

In particular, two scaling relations have been found to determine the forms of trees (Borchert & Honda, 1984; Kira, 1978; McMahon & Kronauer, 1976; Turrell, 1961). The first scales the diameter of a branch or trunk to its length so that the ratio of tree height to trunk diameter is specific to the height of a tree. The second scales the number of branches to the height of a tree. Both properties of tree form, the height-to-diameter ratio and the num-ber of branches, are well preserved in optical images. As such, they might provide visual information about the size of trees.

Bingham (in press-b) investigated this possibility by using the two scaling relations to generate simulated tree silhouettes of constant image size for trees in six different tree architectures. Modeled heights ranged from 15 to 90 ft. Observers were shown tree silhouettes on a white and otherwise unstructured background. No information about distance was provided. According to the size-distance invariance theory, no information about size should have been available (Boring, 1940; Gogel, 1977; Kilpatrick & Ittelson, 1953). Although the observers strongly underestimated the taller trees, judgments of the shorter trees were fairly accurate and increased monotonically with actual sizes. Nevertheless, when compared with estimates of the heights of real trees viewed in normal viewing conditions, the estimates of the simulations exhibited much greater numbers of random and systematic errors.

The application of scaling relations to generate tree forms in simulations was strictly deterministic. However, the physical laws act in nature to determine only limiting conditions that are approached in actual instances (McMahon, 1975; McMahon & Bonner, 1983; Niklas, 1992). The physical laws determine the functional form of the scaling relations, but the values of the coefficients vary within a restricted range, depending on local conditions of soil, rainfall, wind, and competition with other trees. Also, architectural variations play a role that is not yet well understood. Given these local variations, the ability to relate particular trees to a common (global) structured field might be essential to allow an observer to tune out the variations, investing the field with the scale regularities apparent in the trees. If the trees appeared in the con-

text of a ground texture gradient, they could be used to scale the ground texture elements with a refinement in the scaling over successively viewed trees.

This reasoning is based on the fact that scaling information will always specify a continuous range of values and not a particular value along the relevant dimension. Measurement is never absolutely precise. Better information is more precise; that is, it specifies a more limited range of values. The question is whether more (of the same) information is more precise. In general, this is a difficult question, but I am suggesting that more information would be better in this case, given a standard of comparison among measurements.

Given a single tree, an observer will estimate a height that is within the range of values specified. With no standard of comparison between measurements, estimates of different trees are free to vary independently over the range of values specified by each subsequent item. Using memory to make comparisons among sequentially observed trees might be very difficult, given the complexity of tree forms. However, if the trees appeared (appropriately located) within a common ground texture gradient, the scale estimate of a given tree could be used to scale the size of the ground texture elements. The scaling of the texture elements would have to be adjusted over subsequent trees, allowing estimates of different trees to interact. At the very least, random errors should be reduced. Lower levels of both systematic and random errors obtained for smaller and closer trees also could constrain systematic errors for the remaining trees.

On the basis of this reasoning, Bingham (in press-b) next showed the observers simulations of tree images appearing in a common ground texture gradient. The result was that both systematic and random errors in height judgments decreased significantly. Mean estimates well approximated actual tree heights up to a ceiling of about 50–60 ft. The presence of this ceiling was perplexing. However, by manipulating the viewing conditions for real trees, this ceiling was replicated. When the observers were required to view real trees through a tube that eliminated both binocular and wide-angle vision, a significant drop in maximum mean estimates resulted. When the observers judged the heights of real trees viewed in photographs, the maximum estimates dropped slightly more, exhibiting the same ceiling as the estimates of simulations. Although the ceiling was associated with the pictorial nature of the simulations, the particular source of the ceiling remains unclear.

To investigate whether the trees might confer a metric on the ground texture gradient, nonbiological objects were included in the simulations with simple unchanging platonic forms. The question was whether the observers could estimate the definite sizes of these nonbiological objects.[1] The gradient, by itself, only would allow the relative sizes of the objects to be determined by a comparison between the images of objects and the neighboring ground texture elements. Tree images might allow the definite size of the ground texture elements to be determined; from these,

in turn, the size of the cylinders might be determined. Seven cylinders of increasing size were placed at increasing distances along the ground so as to preserve their image size. Different trees appeared in the context of the same set of cylinders as well as the same texture gradient. The result was that estimates of cylinder heights were fairly accurate. Mean judgments overestimated the smallest cylinders by about 1.5 ft, presumably due to a floor effect, whereas mean estimates of larger cylinders were accurate. Random errors were comparable to those for tree judgments.

By including a ground texture gradient with a horizon in the simulations, the possibility that the observers had used the horizon ratio to improve their estimates of definite sizes was introduced. Because the image of the horizon crosses the images of objects along the ground at a height corresponding to the eye height of the observer, the ratio of this height in the image to the full image height of the object might be used to determine an object's actual size (Sedgwick, 1980; Warren & Whang, 1987). This would require that the height of the point of observation be known. To the extent that the eye height of a standing, walking, or running observer is constant, the horizon ratio hypothesis is similar to the hypothesis that the distance between the two eyes is used to scale distances via binocular convergence. However, to the extent that eye height varies with posture and the height of support surfaces, the horizon ratio hypothesis better resembles the observation that if the velocity of the point of observation was known, then distance might be definitely scaled via motion parallax (Koenderink, 1986; Nakayama & Loomis, 1974). The problem in the latter case is that no information about eye velocity has been shown to be available. Likewise, a lack of information about eye height in various contexts simply transfers the problem of scaling size to the problem of scaling eye height. Nevertheless, there is evidence supporting the horizon ratio hypothesis (Mark, 1987; Rogers & Costall, 1983; Warren, 1984; Warren & Whang, 1987).

To investigate the possible use of the horizon ratio to judge the heights of simulated trees and cylinders, additional observers were shown only the cylinders in the context of the gradient and asked to judge cylinder height. A point of observation 1.7 m above the ground was used to generate all simulations, both with and without trees. This height approximated the mean eye height of a standing observer. If the observers used the horizon ratio, the judgments of cylinders without trees should have been comparable in accuracy to judgments with trees. However, they were not. The numbers of both systematic and random errors were considerably greater. The additional possibility that the difference in cylinder estimates with and without trees was produced by a practice effect remained, because the cylinders were viewed 46 times together with various trees and only once without them. To control for this possibility, the cylinders-with-trees condition was replicated, using 52 poles instead of trees; the poles spanned the same range of heights as the trees. The

results for both the poles and the cylinders were the worst yet. The implication of the combined results was that the scale was derived from the apprehension of the trees.

The purpose of the present study was to test further both the horizon ratio hypothesis and the tree form hypothesis. First, the previous study (Bingham, in press-b) was replicated by using simulations generated with the point of observation 4 m above the ground instead. If observers use the horizon ratio with an assumed eye height determined by their own dimensions, with a doubling of the eye height used to generate simulations, the slope of the judgment curves should be cut in half.

Both the present and previous studies were performed by using images on sheets of paper that were viewed on a tabletop by seated observers. These viewing conditions did not preserve actual visual angles and gaze orientations that would be intrinsic to normal viewing of real trees. In Experiment 2, the simulations generated with a 1.7-m high point of observation were used, and observers viewed displays in conditions that preserved appropriate viewing angles and gaze orientations. The use of the horizon ratio might depend on these viewing conditions. Another purpose of the study was to determine whether these viewing conditions might affect the ceiling in judgments of tree height.

EXPERIMENT 1
Four-Meter Eye Height

Observers were asked to estimate the heights of trees appearing in simulated images. Simulated tree forms were generated by using two scaling relations—one determining the relation between height and diameter and the other the relation between height and number of branches. Tree silhouettes of constant image height appeared in a ground texture gradient simulating a flat plain. The observers were asked to judge the heights of cylinders also appearing on the plain to test whether the trees might confer a metric on the texture gradient. The images were generated by using a simulated eye height of 4 m. The results were to be compared with previously obtained results (Bingham, in press-b) using images generated with a 1.7-m simulated eye height. If the observers used the horizon ratio with an assumed eye height determined by their own dimensions, then the slopes of the judgment curves for both trees and cylinders would be expected to drop to about 42% of the slopes previously obtained.

Method

Participants. Sixteen graduate and undergraduate students at Indiana University participated in the study. Half were male and half were female. None had participated in Bingham's (in press-b) earlier studies. All had normal or corrected-to-normal vision. The participants were paid $4.25/h.

Display generation. Simulated tree images were generated in the same way as in Bingham (in press-b), with a change in the height of the simulated point of observation. A program used by Borchert and Honda (1984) was modified to generate simulations of tree branching processes. This program produced images of stick fig-

ure trees in architectures determined by varying branch angles and lengths. The program simulated hydrodynamic processes (Zimmermann, 1978a, 1978b), which constrain branch numbers to conform to a square law of increase. Routines were added to determine branch and trunk thicknesses according to the scaling relation described by Kira (1978). This hyperbolic relation asymptotes at maximum tree heights appropriate to specific climate zones. A maximum tree height of 40 m was used, which is appropriate for temperate-zone trees (see Kira, 1978). Images of 46 trees in six different architectures were generated, spanning a range of heights from 15 to 90 ft.

All the tree silhouettes were placed in the same ground texture gradient. Ground texture elements had the appearance and size of weeds, somewhat like crabgrass. The trees were located at a distance along the ground that preserved tree image height at 11° of visual angle for a point of observation located 4 m above the ground. The tree branches and circular cross-sections of trunks were generated in three-dimensional space and these were projected to the images via polar projection.

Also, as in Bingham (in press-b), seven cylinders were placed at various locations along the ground, covarying in size and distance so as to preserve image size. However, the increase in the height of the point of observation from 1.7 to 4 m resulted in more of the nearer ground surface being occluded by the viewing window. Because of this, the range of cylinder sizes (and distances) was altered from 1–10 ft to 3–14 ft to preserve the image size and the approximate locations of the cylinders within the image to replicate that used previously. The layout of both texture elements and cylinders was the same in all 4-m eye-height images; the trees were placed at various distances along the midline of the image. The images, projected to 1.7-m versus 4-m eye height, can be compared in Figure 1.

Procedure. As in Bingham (in press-b), the observers first judged the height, in feet, of 16 real trees observed on the IU campus at distances preserving constant image heights of 32° of visual angle. In pilot studies, participants had been observed to estimate their eye heights at the base of a tree and then, using this as a yardstick, move successively up the tree by eye. It was subsequently mentioned to the observers that tree height might be estimated in this manner, but that they should not do so. Rather, they were instructed to keep their eyes to the ground until they were placed in the desired location for judging a given tree. The tree was then pointed out to them and they were asked to produce an off-the-cuff estimate within about 2–3 sec after merely glancing at the tree—enough time to take in its form. Producing estimates in such a brief interval did not allow the use of the more explicit measurement technique. Before making judgments, the observers were shown two lighting poles of 26 and 64 ft in height, respectively, and were told the heights in feet. The lighting poles were never in view together with any of the trees to be judged. The actual heights of the real trees ranged from 10 to 90 ft.

Next, the observers returned to the laboratory and judged the heights of the trees in the simulated tree images. They were given a packet in which the images of the 46 trees were stapled together in a random order, intermixing trees from different architectures within the order. Two different random orderings were used. The observers were instructed to flip through the images in order and to write estimates of height, in feet, on another sheet of paper. After they had completed the entire packet, they were allowed to go back freely through the images and write any adjusted estimates they wished next to their original estimates. Eighty percent of the adjusted estimates were within ±5 ft of initial estimates, and 89% were within ±10 ft. (These values were 79% and 90% for the 1.7-m simulated eye-height data.)

After having judged the 46 simulated tree images, the observers were asked to judge the heights of the cylinders that had appeared in all of the images. To make their judgments, they were allowed to flip once again through the packet of tree images, examining the
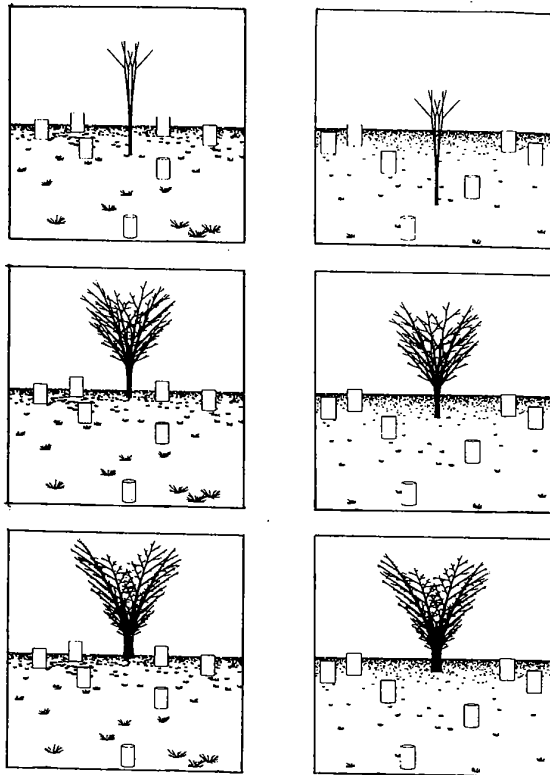
Figure 1. Simulated tree images projected to simulated eye heights of 1.7 m (left) and 4 m (right). From top to bottom, in both cases, the shortest, midsized, and tallest trees in architecture C (Bingham, in press-b) are shown. Image sizes were kept the same, so trees of like size were viewed from the same distances for both eye heights. However, less of the foreground was visible at the 4-m eye height, so the sizes and distances of the cylinders had to be changed. The number and approximate image locations of the cylinders were preserved, and the range of cylinder heights was kept as close to the original range as possible. The sizes of the largest three cylinders at the 1.7-m eye height were the same as the middle three cylinders at the 4-m eye height.

cylinders in the context of the different trees. The observers were shown an image of the cylinders and texture gradient without trees, in which the cylinders were labeled 1–7 in a random order. These labels were used to refer to the cylinders on a protocol sheet, used by the observers to record their estimates.

Results and Discussion

The judgments of the real trees replicated in Bingham's (in press-b) previous results. When the judged heights were regressed linearly on actual heights, the slope was .94, the intercept was .30, and the r^2 was .80. The previously obtained values were .94, −1.13, and .80, respectively.

The estimates of the simulated trees replicated the previous results, in all respects, except for one. The focal question was whether doubling the simulated eye height would halve the slope of height estimates for simulated trees. It did not. The slope of the judgment curves was unaffected by the eye-height manipulation. On the other

hand, the intercept was lowered directly in proportion to the increase in simulated eye height. A linear regression of modeled tree heights on judged heights yielded a slope of .54, an intercept of 2.2, and an r^2 of .54. The corresponding values for a simulated eye height of 1.7 m were .50, 11.4, and .40, respectively. [The mean r^2 when linear regressions were performed separately for each observer were .78 ($SD = .13$) and .75 ($SD = .10$) for 4-m and 1.7-m eye heights, respectively.] When modeled height was regressed on the combined judgments in a multiple regression with vectors coding (using orthogonal coding) for simulated eye height and the interaction, the result was significant [$F(3,1652) = 520.4$, $r^2 = .49$, $p < .001$] and both modeled height ($\beta = .66$, partial $F = 1392.5$, $p < .001$), and eye height ($\beta = .27$, partial $F = 44.4$, $p < .001$) were significant. The interaction was not significant ($\beta = .06$). Thus, the intercepts were different but the slopes were not. As shown in Figure 2, this result was also reflected in a linear regression of mean judgments for the 1.7-m simulated eye height on mean judgments of the 4-m eye height. The slope was essentially 1, but the intercept was different from 0, reflecting a drop of 9 ft for judgments in the 4-m condition. Mean judgments for all the trees dropped by about 2.4 m with a rise in the simulated eye height of 2.3 m.

In all other respects, the results of the current experiment were the same as those reported in Bingham (in press-b). (See Bingham, in press-b, for an additional discussion of the following results.) Based on a relation that scaled trunk diameter as a hyperbolic function of tree height (Kira, 1978), a linear relation between tree height and the height-to-diameter ratio (H/D) was obtained. The ratio also describes the form of a tree along its branches and trunk. Because this ratio is well preserved in optical images and because it scales to actual tree height, it provides potential information about tree height. The inter-

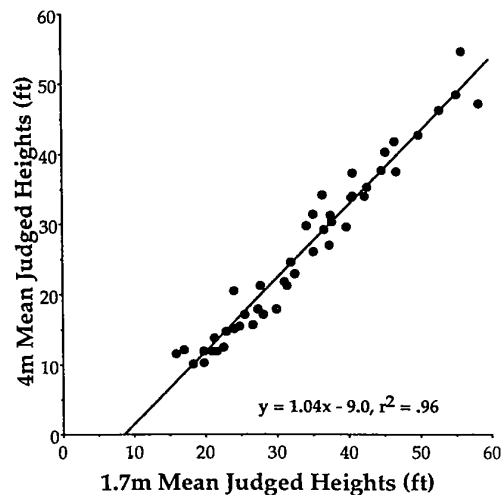$$y = 1.04x - 9.0, \; r^2 = .96$$

Figure 2. Mean height estimates of 46 trees viewed at a simulated eye height of 4 m plotted against those viewed at a simulated eye height of 1.7 m.

cept in the linear relation between H/D and tree height represents the maximum tree height. When the H/D ratio was regressed linearly on mean judgments, the intercept was 60.0 and the r^2 was .78. The corresponding values for the 1.7-m eye height were 63.9 and .72, respectively. Higher order terms in polynomial regressions failed to reach significance in both cases. The ceiling for maximum mean judgments was equally apparent.

Tree height also scaled with the square of the number of branches. This is another property of tree form that is well preserved in tree images. If the observers used this information, the relation between the square root of the number of branches and judgments would be linear. When $N^{.5}$ (N = number of branches) was regressed on mean judgments, the r^2 of .87 was comparable to that for 1.7-m eye height (r^2 =.84). In both cases, when a polynomial regression was performed, the second order term was not as significant as it was when the regression was performed by simply using N.

When H/D and $N^{.5}$ were regressed simultaneously on mean judgments, the result was significant (r^2 = .88, $p <$ .001). Only $N^{.5}$ was significant (β = .73, partial F = 37.9, $p <$ .001). The β for H/D was $-.22$. This reproduced the pattern that resulted when this regression was performed on either modeled heights or mean judgments with 1.7-m simulated eye height.

As before, it was expected that the ground texture gradient would allow the observers to use the information about scale that they obtained in apprehension of successive trees to gradually tune the scaling of the gradient. To investigate this possibility, the pattern over presentation order of mean percent absolute error in the initial set of judgments was once again examined. Errors decreased over trials. A linear regression of order of presentation on mean percent absolute error was significant (r^2 = .41, $p <$ .001), with a slope of $-.32$. This result was identical to that previously obtained for judgments of trees with a ground texture gradient. No such relation had been found for judgments of trees appearing without the ground texture gradient. The presence of the texture gradient enabled the observers to improve the accuracy of their estimates over trials.

Judgments of cylinders. Bingham (in press-b) tested the two alternative means by which observers might have determined the size of the cylinders in simulations. If they used the horizon ratio, accurate estimates of the cylinders should have been possible without having viewed the trees. On the other hand, if the observers used the trees to scale the gradient and the cylinders, apprehension of the trees should have resulted in more accurate cylinder estimates. The number of errors was considerably greater when they judged the cylinders without viewing the trees. When modeled heights were regressed on judgments, the variability in slopes for individual observers was more than double, the variability in intercepts was four times greater, and the overall r^2 was less than a quarter of the value obtained when the observers did view the trees.

On the basis of this result, it was concluded that the observers must have used the trees to scale the gradient and the cylinders. Although the tree judgments did not exceed a ceiling with a resulting underestimation of tall trees, the mean judgments of trees up to about 50-60 ft were fairly accurate. Because the latter trees overlapped in distance with the cylinders, comparably accurate cylinder judgments would have been expected. As shown in Figure 3, the slope of cylinder estimates, at .68, was shallow. Mean estimates overestimated smaller cylinders and accurately estimated larger cylinders. The observers expressed their estimates in feet. Because of a tendency to use integer values, no estimates were below 1 ft; the smallest cylinder was 1 ft tall. It was concluded that mean overestimations of the smaller cylinders were the product of a floor effect. The mean estimate of the smallest cylinder was 2.5 ft. Each successively larger cylinder was correctly estimated as being larger than the preceding smaller one. As the cylinders began to overlap in distance with the trees, cylinder judgments ceased to overestimate modeled heights. For the three tallest cylinders, the ratio of mean judged to actual height was .97 (SD = .08); for trees in the same range of distances, the ratio was .78 (SD = .07).

As shown in Figure 3, with the increase in simulated eye height to 4 m, the mean cylinder estimates decreased. Linear regression of actual heights on judged heights was significant (r^2 = .38, $p <$ .001), with a slope of .46 and an intercept of 2.17. A multiple regression of modeled heights on combined judgments for both simulated eye heights with vectors coding for eye height and the inter-
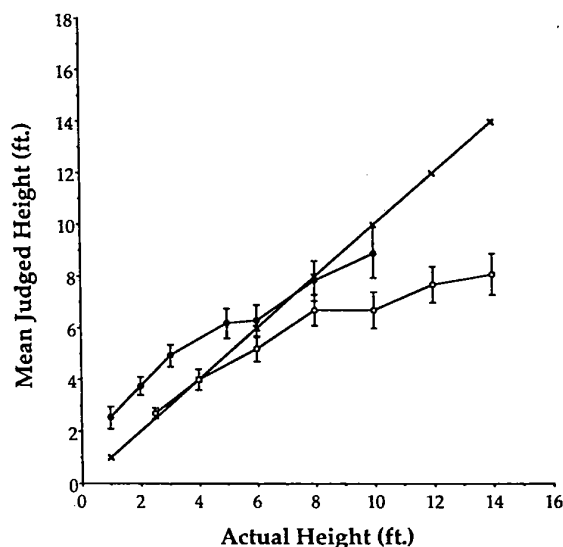

Figure 3. Mean height estimates (with standard error bars) of cylinders viewed at simulated eye heights of 1.7 m (filled circles) and 4 m (open circles) plotted against modeled heights. A line (crosses) indicating perfect correspondence is also shown.

action was significant ($r^2 = .35, p < .001$). Modeled height was significant ($\beta = .66$, partial $F = 135.0, p < .001$), as was the interaction ($\beta = .27$, partial $F = 6.0, p < .02$). Eye height was not significant ($\beta = .04$). Thus, the decrease in cylinder judgments was produced by a drop in slope, but no change in intercept. The intercepts in both instances were just greater than 2. It was inferred that the floor effect occurred in both instances. How could the decrease in slope be accounted for?

The change in simulated eye height decreased mean height estimates of all the trees by a constant amount. However, the proportional changes in judged heights were different for different heights at different distances along the ground. Therefore, the change in scaling along the texture gradient was nonhomogeneous. Nevertheless, extrapolating from the observers' demonstrated ability to tune out architectural variability to arrive at a homogeneous scaling of the gradient, it was inferred that the scaling of the gradient and the cylinders would reflect the mean proportional change defined across the changes in all trees. The mean proportional drop in tree heights was .25. This contrasted with the change in slope predicted by the horizon ratio hypothesis for a change in simulated eye heights from 1.7 to 4 m. The predicted change was .39—more than 1.5 times that predicted from the change in judged tree heights. The slope for cylinder estimates dropped from .68 to .46—a change of .22. This change was comparable to that predicted by tree judgments and supported the hypothesis that the scaling of the cylinders was derived from apprehension of the trees. Once again, as the cylinders began to overlap in distance with the trees, they increasingly scaled like the trees. The ratio of mean judged to modeled heights for the three tallest cylinders was .61 ($SD = .04$), whereas for trees at the same range of distances the ratio was .58 ($SD = .03$).

Although the horizon ratio hypothesis was not supported by these results, there certainly was an effect of the change in simulated eye height. The change was in the intercept rather than the slope of the tree estimates. The decrease in mean estimates was equal to the increase in simulated eye height. The only sense that could be made of this was that the observers used the horizon relation to determine the height of the trunk from the ground to the point of intersection with the horizon, scaling this distance according to their eye height when standing. The remainder of the tree was scaled according to the tree form, or similitude, hypothesis. (This possibility was mentioned in Appendix B of Bingham, in press-b, as a strategy that would eliminate errors associated with variation in viewing distance.)

Of course, if the horizon was used in this way with the trees, then it should have been used similarly with the cylinders. Rogers and Costall (1983) investigated observers' use of the horizon to determine the relative size of objects in pictures and found that the horizon was used when objects were tall enough to intersect the horizon, but not otherwise. Thus, the horizon might have been used only with the cylinders that were tall enough to intersect the horizon, and then only to determine height from the ground to the point of intersection. (After all, if the constant decrement found in height estimates of trees were applied to all of the cylinders, including those not tall enough to intersect the horizon, heights less than zero would have resulted.) Thus, another account of the slope change for the cylinders might be that only the cylinders tall enough to intersect the horizon line were affected by the change in eye height. The estimates of the smallest cylinders were unaffected by the eye-height change, both because their images did not reach the horizon line and the estimates were constrained by the floor effect. As a result, the curve rotated about its low end.

However, if the horizon did play a role in the judgments of cylinders tall enough to intersect the horizon, it was a fairly weak role because the variability in estimates did not decrease for those cylinders. When the observers viewed only the cylinders and no trees, the standard deviations were equally large for all the cylinders. For the judgments performed with trees at both simulated eye heights, standard deviations continued to increase with cylinder height, even in both conditions for cylinders that were just tall enough for their images to touch the horizon.

It was concluded that the horizon was used in very restricted ways, and successful estimates of heights were achieved by using variations in the forms of trees as information.

EXPERIMENT 2
Eye Height, Visual Angle, and Gaze Level

In Experiment 1 and Bingham (in press-b), simulations were presented to observers as images on paper placed on a tabletop. The observers sat at the table to view the images and to write their estimates. These viewing conditions did not preserve the visual angles or gaze levels appropriate for viewing the simulations as if one were viewing actual trees. Although a visual angle of 11° had been used in projecting simulated trees to the tree images (i.e., assuming the projection surface to be a certain fixed distance in front of the point of observation), the actual visual angles subtended by the tree images, as viewed by the observers, were not controlled. Furthermore, although the images had been projected to a point of observation simulated to be 1.7 m (or 4 m) above the ground surface, the seated observers viewed the images from considerably shorter eye heights and their actual direction of gaze was radically different from that appropriate to standing and looking out across a ground surface. Perhaps these conditions interfered with the ability and/or inclination of the observers to use the horizon ratio, as they normally might, to judge real trees.

To investigate this possibility, the final experiment reported in Bingham (in press-b) was replicated, with a change only in viewing conditions. Viewing conditions that preserved the correct viewing angles, eye heights, and gaze levels were used to simulate observers standing on a ground-level floor and viewing the scene through

a large picture window. The images were the same as those used in Bingham (in press-b). As before, the participants first judged real trees, then simulated trees, and then the simulated cylinders. A separate group of observers judged only the simulated cylinders. As before, the results in judging cylinders with and without viewing trees were compared. A comparison was also made between the "on-paper" and "through-a-window" viewing conditions.

Method

Participants. Sixteen graduate and undergraduate students at Indiana University participated in judging both the trees and cylinders. Another group of 16 students participated in judging only the cylinders. In both instances, half were male and half were female. All the participants had normal or corrected-to-normal vision. None had participated in the earlier experiments. The participants were paid $4.25/h.

Displays. The images from Experiment 3 of Bingham (in press-b) were used, which were the same as described for the present Experiment 1, except that the simulated trees had been projected to a simulated eye height of 1.7 m. Sample images appear in Figure 1. A separate image contained the cylinders and ground texture gradient without any trees.

Procedure. As in Experiment 1, the observers first judged the heights of 16 real trees on the IU campus and then judged the heights of the 46 simulated trees. The images were projected onto a large, flat, white screen in a large darkened lecture hall. The screen extended from the floor to the ceiling. The images were transferred onto transparencies. An opaque frame was placed onto the overhead projector, framing the simulated image so that only the image itself was projected onto the screen. The size of the image on the screen was 1.22 × 1.22 m. The bottom of the image was 1.22 m from the floor so that the horizon in the image was 1.7 m above the floor. The observers stood, 2 at a time, on a level wooden floor, leaning against or sitting on a desk so that their eye height was as close to 1.7 m above the floor as possible. The taller observers leaned against the desk to lower their eye height, and the shorter observers sat on the desk to raise their eye height. The observers perched on opposite corners of the desk, about .6 m apart from one another. They were located at a distance of 2.5 m from the screen so that the tree images subtended a height of 14° of visual angle.

The observers were instructed to approach the situation as if they were looking through a large window at a scene existing outside of the room. First, they were asked to judge the height of the trees in feet. They were instructed to not look at one another's estimates. The observers also closed their eyes while the images were changed from one to the next. The tree images were presented in one of two different random orders. After the observers had judged all 46 trees, the order was repeated and they were allowed to write adjusted estimates next to their original estimates if they wished. Seventy percent of the adjusted estimates were within ±5 ft of their corresponding initial estimates, and 86% were within ±10 ft.

After having judged the simulated tree images, the observers were asked to judge the heights of the cylinders that had appeared in all of the tree images. They were shown an image of the cylinders (and texture gradient) without trees. The cylinders were labeled 1-7 in a random order by the experimenter, who pointed to them in order. These labels were used to refer to the cylinders on a protocol sheet used by the observers to write their estimates. The observers were then shown a selection of the tree images once again so that they could view the cylinders in the context of the trees while they made their estimates.

The observers who judged the heights of cylinders without viewing the trees were shown only the image of the cylinders and gradient without trees. The viewing conditions and instructions were otherwise the same as in Experiment 1.

Results and Discussion

The results were generally the same as those obtained when the observers had judged the same images viewed on paper, with some decrease in random errors.

When modeled tree heights were regressed linearly on judgments, the result was significant ($r^2 = .54$, $p < .001$), with a slope of .47 and an intercept of 8.5. The comparable results for the "on-paper" viewing were $r^2 = .40$, with a slope of .50 and an intercept of 11.4. The mean r^2 for regressions performed separately for each observer was .74 ($SD = .16$) compared with .75 ($SD = .10$) for on-paper viewing. Outlying r^2 values, which were about half those of the remainder, were produced by 3 of the observers. When these were excluded, the mean r^2 rose to .80 ($SD = .08$), with a mean slope and intercept of .53 and 7.4, respectively. When modeled heights were regressed simultaneously on the combined judgments for on-paper and through-a-window viewing, with vectors coding (orthogonal) for viewing condition and the interaction, the result was significant ($r^2 = .46$, $p < .001$). Both modeled height ($\beta = .66$, partial $F = 1315.2$, $p < .001$) and viewing condition ($\beta = .09$, partial $F = 4.8$, $p < .03$) were significant, but the interaction was not ($\beta = .06$). Thus, the intercepts were different, although the slopes were not. As shown in Figure 4, when mean judgments for each tree in the two viewing conditions were regressed on one another, the slope was near 1, but the intercept revealed a drop of about 3 ft in through-a-window viewing. This difference was consistent with a change in (assumed) eye height from a seated to a standing posture, given an understanding of the use of the horizon ratio; that is, using the horizon ratio to gauge only that portion of the tree extending below the horizon line. Nevertheless, given the potential confounds in simultaneously changing from on-paper to through-a-window

$$y = 1.05x + 3.2, r^2 = .93$$

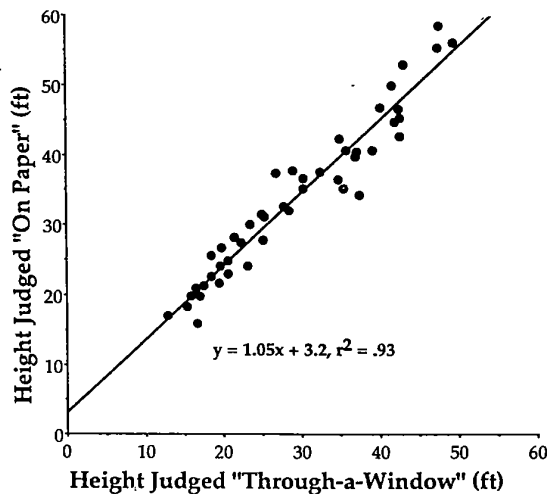Height Judged "Through-a-Window" (ft)

Figure 4. Mean height estimates of 46 trees viewed "on paper" plotted against those viewed as if "through a window." In both cases, simulated tree images were projected to a simulated eye height of 1.7 m.

viewing, this should be investigated by using both seated and standing observers in through-a-window viewing.

The ceiling on mean height judgments was equally apparent for both through-a-window and on-paper viewing. When the H/D ratio was regressed on mean estimates, the only differences in the two viewing conditions were a drop in the intercept representing maximum tree height from 64 to 59 ft and an increase in r^2 from .72 to .82. The results for N^5 were likewise comparable; r^2s were .85 and .84, respectively. When H/D ratio and N^5 were regressed simultaneously on mean estimates in through-a-window viewing, the r^2 was .90, and both H/D ($\beta = -.31$, partial $F = 8.3, p < .01$) and N^5 ($\beta = .66$, partial $F = 36.6, p < .001$) were significant. Finally, a regression of presentation order on mean percentage of absolute errors was significant ($r^2 = .25, p < .01$), with a slope of $-.22$. These results were all comparable to those obtained with on-paper viewing.

When modeled cylinder heights were regressed linearly on cylinder estimates, the result was significant ($r^2 = .42$, $p < .001$), with a slope of .88 and an intercept of 1.77 ft. As shown in Figure 5, this slope was slightly steeper than that obtained with on-paper viewing. However, when modeled heights were regressed simultaneously on the combined estimates for both viewing conditions with vectors coding (orthogonal) for viewing condition and the interaction, the overall result was significant ($r^2 = .39$, $p < .001$) but among the factors, only modeled height was significant ($\beta = .63$, partial $F = 157.5, p < .001$). Neither the slope nor the intercept difference was significant. The r^2 of .42 from the simple linear regression was comparable to the .35 obtained from the on-paper viewing.
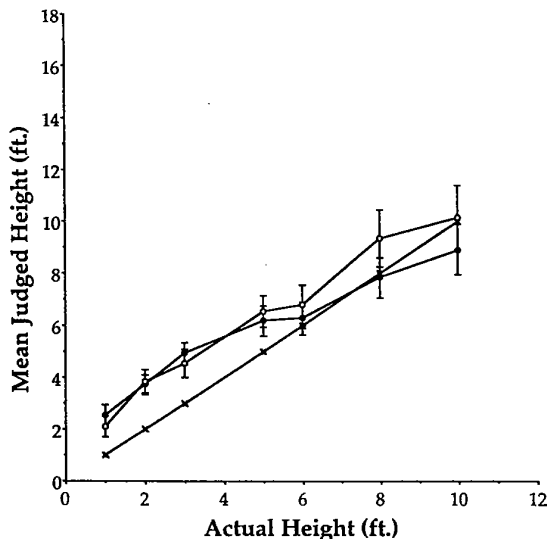

Figure 5. Mean height estimates (with standard error bars) of cylinders viewed "on paper" (filled circles) and "through a window" (open circles) plotted against modeled heights. In both cases, cylinders were viewed together with trees. A line (crosses) indicating perfect correspondence is also shown.

Likewise, when regressions were performed separately for each observer, the mean r^2 in the two viewing conditions were the same—.81 ($SD = .23$) and .82 ($SD = .25$), respectively. The variability in slopes and intercepts was comparable, as shown by standard deviations of .54 versus .60 for slopes and 1.96 and 2.05 for intercepts.

When cylinder heights were judged in through-a-window viewing without seeing the cylinders in the context of trees, the results were also comparable to those obtained with on-paper viewing. As shown in Figure 6, both systematic and random errors were substantially greater for the estimates made without trees than with trees. When modeled heights were regressed linearly on estimates, the r^2 was greater than for on-paper viewing—.21 and .08, respectively—but this was still only half that obtained with trees. The slope of 1.19 and intercept of 2.29 were comparable to those obtained with on-paper viewing—.92 and 3.25, respectively. When regressions were performed separately for each observer, the mean r^2 of .73 ($SD = .32$) was comparable to that obtained for on-paper viewing (.78; $SD = .29$). The variability in slopes for through-a-window viewing was somewhat greater than for on-paper viewing ($SD = 1.35$ vs. 1.15, respectively), but the variability in intercepts was considerably less ($SD = 2.82$ vs. 7.50, respectively). Thus, although the mean slopes for the cylinders estimated without trees were near 1, the individual slopes were highly variable for both viewing conditions. Intercepts, however, were less variable in through-a-window viewing, in which the observers were much less inclined to assign to the smallest cylinder a value greater than their eye height. The implication was that the observers consistently used their ability to see the top of the smallest cylinder to constrain their judgments, but not the relation of the largest cylinders to the horizon line.

GENERAL DISCUSSION

The possibility that observers had used the horizon ratio to scale the estimates of tree and cylinder heights reported in Bingham (in press-b) was investigated. In Experiment 1, the eye height to which simulated trees were projected in images was more than doubled. Viewing conditions were otherwise unaltered. The observers viewed images on paper while seated at a table. Using the horizon ratio to judge definite sizes would require the use of a known eye height, presumably determined by observer dimensions. Assuming that mean observer dimensions, and thus the mean assumed eye-height value, remained unchanged, the horizon ratio hypothesis predicted that mean height estimates should have dropped to 42% of their previous value with the increase in simulated eye height from 1.7 to 4 m. (Mean observer height was 1.72 m, $SD = .10$ and .09, respectively, in both cases.) Tree estimates did not exhibit the expected slope change. However, mean estimates did drop by a constant amount that was equal to the increase in simulated eye height. It was inferred from this that the observers had used the
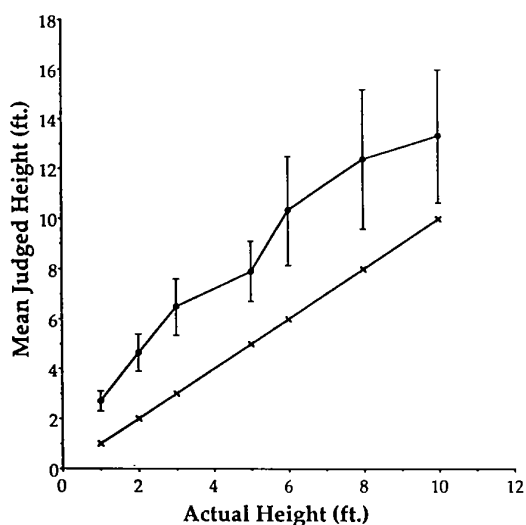
Figure 6. Mean height estimates (with standard error bars) of cylinders viewed "through a window," without trees, plotted against modeled heights. A line indicating perfect correspondence is also shown.

horizon to determine the size of the portion of trunks extending from the ground to the point of intersection with the horizon. The size of the remainder of the tree extending above this point was, by inference, determined by using the form of the tree, including the branch number and the H/D ratio.[2] To gauge the height of the upper portion of a tree, the observers could have used the trunk diameter and height determined from the point of intersection with the horizon. Variations in eye height aside, this strategy would yield more accurate estimates of tree sizes for trees of all heights viewed at all distances (Bingham, in press-b, Appendix B). Introduction of unappreciated or incorrectly gauged variations in eye height would perturb the accuracy of estimates, as occurred in the present experiment.

The change in simulated eye height altered the estimates of cylinder heights proportionally rather than by a constant amount. The proportion, however, was not that predicted by the horizon ratio hypothesis. For instance, the top three and middle three cylinders in the two conditions were of the same modeled heights—6, 8, and 10 ft. In the 4-m eye-height condition, the mean estimates of these cylinders dropped to 83% of the mean estimates in the 1.7-m condition, rather than to 42% as predicted by the horizon ratio hypothesis. The proportional decrease in cylinder estimates was equivalent to the average proportional decrease in tree estimates. This suggested that scaling gleaned from the trees had been used to determine cylinder heights. On the other hand, cylinder judgments may have been subject to a more extensive floor effect, which might have prevented a larger drop in estimates required using the horizon ratio. Perhaps the estimates for the tallest cylinders, which reached the horizon line, were deter-

mined by using the horizon ratio, but the shorter cylinders remained unaffected because they did not reach the horizon line and were held constant by a floor effect. The fourth largest and second largest cylinders in the 1.7-m and 4-m conditions, respectively, just reached the horizon line in the images. According to the horizon ratio hypothesis, these should have been judged as being of a height equal to the observers' eye height. The mean estimates were 6.2 and 7.5 ft, both of which were greater than the mean height of our observers—5.7 ft—although not by more than 1 standard deviation. However, the horizon was equally available to the observers who judged the cylinders without the benefit of seeing them in the context of trees. The substantial size of the random errors in this condition indicated that any effect of the horizon on judgments was very weak, at least until other information about absolute scale was available.

Perhaps, on the other hand, the use of the horizon ratio was undermined by the viewing conditions; that is, observing images on paper while seated at a table. This possibility was investigated by obtaining judgments of trees and cylinders projected to a simulated eye height of 1.7 m in viewing conditions that preserved the appropriate eye height, visual angle, and gaze orientation. The original results (Bingham, in press-b) were replicated in most respects, including the large random errors in judgments of cylinders made without the context of the trees. Although mean tree estimates dropped by a constant 3 ft, this was very small in the context of the relevant range of heights. There was no change in mean cylinder estimates. The only effect of the change in viewing conditions was a decrease in random errors. Overall r^2 increased by 35% for trees and by 20% for cylinders viewed together with trees. Because the slopes did not change, these increases could be attributed to decreases in random error. These might be attributed, in turn, to appropriate visual angles, eye heights, and gaze orientations. Nevertheless, the results did not indicate that the horizon ratio was a powerful determinant of the accuracy of tree judgments when trees appeared within the context of a ground texture gradient.

Although the present results allow some role for the horizon in size judgments, they do not support the horizon ratio hypothesis very well. Recent results, which have been interpreted as being supportive of the hypothesis, did not actually involve the use an explicit horizon. Although Gibson (1950, 1979) did include a horizon in his studies on the perception of size at larger distances, he did not control for alternative possible sources of information, and he did not explicitly manipulate eye height. Rogers and Costall (1983) also included a horizon in their pictorial displays, but they investigated relative size judgments rather than definite size. The best evidence for the use of the horizon ratio has been provided in studies by Warren and Whang (1987) and Mark (1987). In both cases, the objects to be judged were near to the observer and of a size comparable to the observer. Warren and Whang studied the perception of the smallest aperture or

doorway passable in walking without turning of the shoulders. They perturbed eye height by surreptitiously raising the floor underneath the aperture. Mark investigated the perception of the maximum seat pan height that could be sat upon without climbing. He perturbed eye height by requiring his observers to stand on blocks. Both manipulations successfully perturbed judgments of size that were well predicted by eye height. However, both studies took place within the confines of a room that occluded the observers' view of an explicit horizon. The investigators in both cases hypothesized that their observers had used an "implicit horizon."

The implicit horizon has been described as the extrapolated locus of infinite density or maximum compression for a texture gradient projected from a level surface, or as the level of the extrapolated point of convergence of parallel lines projected from horizontal edges viewed in depth (Warren & Whang, 1987). Thus, in a well-constructed room (Runeson, 1988), the implicit horizon would be determined by extrapolating the texture gradient projected from the floor. The problem with this notion is that it only works with level surfaces. When the field of view is filled with the slanted surfaces of hills, mountains, rooftops, or foliage, multiple loci of convergence are specified. (See, e.g., Figure 60, p. 139, in Gibson, 1950.) In fact, multiple loci of convergence will exist in any surrounding containing other than horizontal surfaces. Finding the implicit horizon requires a means of determining the level surfaces in the surround. This seems less problematic in the context of a regular rectangular room.[3] Nevertheless, in principle, the problem is the same in a room as it would be along the Appalachian Trail, surrounded by the ascending slopes of the White Mountains of New Hampshire. Furthermore, the problem also applies to an explicit horizon. An optical horizon line projected from a hilltop need not intersect the image of objects at a height above the ground corresponding to the observer's eye height.[4] An explicit horizon must be verified as lying at the margin of a level ground surface. Thus, whether the horizon is explicit or implicit, appeal must be made to some additional source of information about the levelness of surfaces.

The need for level surfaces indicates that, even if the horizon ratio is used in some circumstances, we should not expect it to be used in all circumstances. Warren and Whang (1987) and Mark (1987) did indeed show that eye-height-related information was used to judge human scaled objects that were close to the observer. However, Mark, Balliett, Craver, Douglas, and Fox (1990) found that, although judgments of maximum seat pan height were initially incorrect with the perturbation of eye height, estimates gradually adjusted over trials until they were once again correct. The especially important finding was that this adjustment did not occur when postural activity was eliminated by requiring observers to lean against a wall. This suggested that optical flow generated by swaying movements of small amplitude were used to make accurate judgments. Optical flow from movements of such small amplitude could not be of much use or relevance for large

objects at significant distances. This finding suggests that the results of both Warren and Whang and Mark may well generalize to human scale objects only at relatively short distances.

To the extent that judgments of maximum seat pan height were a function of eye height, the results of Mark et al. (1990) imply that their observers, when allowed to move, obtained information about the change in their eye height. How movements might reveal eye height remains a mystery. Together with difficulties associated with unlevel surfaces, the primary weakness of the horizon ratio hypothesis is the requirement that eye height be either perceptible or invariant. Because eye height is not invariant, its current value must be perceptible if the horizon ratio hypothesis is to be truly viable. Perception of eye height is yet another scaling problem, exactly like the original scaling problem that we are trying to solve.

The metrics associated with spatial dimensions are lost in the mapping from objects and events (including the observer's own activities) into optical pattern. What information allows such scale to be apprehended nevertheless? The information about eye height seems to be available via observer motion. Motion parallax would provide information about a distance like eye height if the momentary velocity of the point of observation was perceptible. However, a source of reliable and accurate information about absolute observer velocity has not been shown to be available (Koenderink, 1986). Therefore, eye height itself is currently a scaling problem as much as a solution to scaling problems. The advantage of the biological form hypothesis is that it is not subject to this sort of regress. The suggestion is that the solution to the size-perception problem originates with the same factors that determine the sizes of the objects perceived. The apparent drawback of this solution is that it is limited to circumstances when biological objects are in view. On the other hand, as suggested in Bingham (in press-a, in press-b), the solution might be extended to kinematic forms, including the forms of motion of an observer, in which case it might provide a basis for the eye-height hypothesis.

We have suggested that the forms of biological objects might provide information about scale because physical laws entail specific alteration of forms for the preservation of function in the face of scale changes. The same constraints that determine the forms of trees also determine the forms of grasses, shrubs, and other plants (Niklas, 1992). Scaling laws determine not only the recognizable shapes of such vegetation, but also the distribution of vegetation over the ground. The thesis that has been advocated in this and the previous (Bingham, in press-b) paper has been contained implicitly in accepted perceptual theory. Ground texture gradients require stochastic regularity in the distribution of the elements on the ground that project to the gradient. The "self-thinning law," which contributes to a determination of the density of branching in trees, applies equally well to a determination of the density and distribution of grass or shrubs along the ground (Norberg, 1988; White, 1981). Ground texture gradients are but another example of how infor-

mation about scale can be found in forms that are determined by scaling laws.

REFERENCES

BINGHAM, G. P. (in press-a). Dynamics and the problem of visual event recognition. In R. Port & T. van Gelder (Eds.), *Mind as motion: Dynamics, behavior and cognition*. Cambridge, MA: MIT Press.

BINGHAM, G. P. (in press-b). Perceiving the size of trees: Form as information about scale. *Journal of Experimental Psychology: Human Perception & Performance*.

BORCHERT, R., & HONDA, H. (1984). Control of development in the bifurcating branch system of tabebuia rosea: A computer simulation. *Botanical Gazette*, 145, 184-195.

BORING, E. G. (1940). Size-constancy and Emmert's law. *American Journal of Psychology*, 53, 293-294.

CALDER, W. A. (1984). *Size, function, and life history*. Cambridge, MA: Harvard University Press.

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

GIBSON, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

GOGEL, W. C. (1977). The metric of visual space. In W. Epstein (Ed.), *Stability and constancy in visual perception* (pp. 129-181). New York: Wiley.

HILDEBRAND, M., BRAMBLE, D. M., LIEM, K. F., & WAKE, D. B. (1985). *Functional vertebrate morphology*. Cambridge, MA: Harvard University Press.

KILPATRICK, F. P., & ITTELSON, W. H. (1953). The size-distance invariance hypothesis. *Psychological Review*, 60, 223-231.

KIRA, T. (1978). Community architecture and organic matter dynamics in tropical lowland rain forests of Southeast Asia with special reference to Pasoh Forest, West Malaysia. In P. B. Tomlinson & M. H. Zimmermann (Eds.), *Tropical trees as living systems* (pp. 561-590). Cambridge: Cambridge University Press.

KOENDERINK, J. J. (1986). Optic flow. *Vision Research*, 26, 161-180.

MARK, L. S. (1987). Eyeheight-scaled information about affordances: A study of sitting and stair climbing. *Journal of Experimental Psychology: Human Perception & Performance*, 13, 683-703.

MARK, L. S., BALLIETT, J. A., CRAVER, K. D., DOUGLAS, S. D., & FOX, T. (1990). What an actor must do in order to perceive the affordance for sitting. *Ecological Psychology*, 2, 325-366.

MATIN, L., & FOX, C. R. (1989). Visually perceived eye level and perceived elevation of objects: Linearly additive influences from visual field pitch and from gravity. *Vision Research*, 29, 315-324.

McMAHON, T. A. (1975). The mechanical design of trees. *Scientific American*, 223, 97-102.

McMAHON, T. A. (1984). *Muscles, reflexes, and locomotion*. Princeton, NJ: Princeton University Press.

McMAHON, T. A., & BONNER, J. T. (1983). *On size and life*. New York: Scientific American Books.

McMAHON, T. A., & KRONAUER, R. E. (1976). Tree structures: Deducing the principle of mechanical design. *Journal of Theoretical Biology*, 59, 443-466.

NAKAYAMA, K., & LOOMIS, J. M. (1974). Optical velocity patterns, velocity sensitive neurons, and space perception: A hypothesis. *Perception*, 3, 63-80.

NIKLAS, K. J. (1992). *Plant biomechanics: An engineering approach to plant form and function*. Chicago: University of Chicago Press.

NORBERG, R. A. (1988). Theory of growth geometry of plants and self-thinning of plant populations: Geometric similarity, elastic similarity and different growth modes of plant parts. *The American Naturalist*, 131, 220-256.

PETERS, R. H. (1983). *The ecological implications of body size*. Cambridge: Cambridge University Press.

ROGERS, S., & COSTALL, A. (1983). On the horizon ratio: Picture perception and Gibson's concept of information. *Leonardo*, 16, 180-182.

RUNESON, S. (1988). The distorted room illusion, equivalent configurations, and the specificity of static optic arrays. *Journal of Experimental Psychology: Human Perception & Performance*, 14, 295-304.

SCHMIDT-NIELSEN, K. (1984). *Scaling: Why is animal size so important?* Cambridge: Cambridge University Press.

SEDGWICK, H. (1980). The geometry of spatial layout in pictorial representation. In M. A. Hagen (Ed.), *The perception of pictures* (Vol. 1, pp. 33-90). New York: Academic Press.

STOPER, A. E., & BAUTISTA, A. (1992, May). *Apparent height as a function of pitched environment and task*. Paper presented at the meeting of the Association for Research in Vision and Ophthalmology, Sarasota, FL.

STOPER, A. E., & COHEN, M. M. (1989). Effect of structured visual environments on apparent eye level. *Perception & Psychophysics*, 46, 469-475.

STOPER, A. E., & COHEN, M. M. (1991). Optical, gravitational and kinesthetic determinants of judged eye level. In S. Ellis, M. Kaiser, & A. Grunwald (Eds.), *Pictorial communication in virtual and real environments*. New York: Taylor & Francis.

SZÜCS, E. (1980). *Similitude and modelling*. Amsterdam: Elsevier.

THOMPSON, D. A. (1961). *On growth and form*. Cambridge: Cambridge University Press.

TURRELL, F. M. (1961). Growth of the photosynthetic area of citrus. *Botanical Gazette*, 122, 284-298.

WAINWRIGHT, S. A., BIGGS, W. D., CURREY, J. D., & GOSLINE, J. M. (1976). *Mechanical design in organisms*. New York: Wiley.

WARREN, W. H. (1984). Perceiving affordances: Visual guidance in stair climbing. *Journal of Experimental Psychology: Human Perception & Performance*, 10, 683-703.

WARREN, W. H., & WHANG, S. (1987). Visual guidance of walking through apertures: Body-scaled information for affordances. *Journal of Experimental Psychology: Human Perception & Performance*, 13, 371-383.

WHITE, J. (1981). The allometric interpretation of the self-thinning rule. *Journal of Theoretical Biology*, 89, 475-500.

ZIMMERMANN, M. H. (1978a). Hydraulic architecture of some diffuse-porous trees. *Canadian Journal of Botany*, 56, 2286-2295.

ZIMMERMANN, M. H. (1978b). Structural requirements for optimal water conduction in tree stems. In P. B. Tomlinson & M. H. Zimmermann (Eds.), *Tropical trees as living systems* (pp. 517-532). Cambridge: Cambridge University Press.

NOTES

1. See Bingham (in press-b) for a discussion of the use of the term *definite* in preference to *absolute*.

2. In pilot studies, some observers did seem to be using eye-height information to gauge the height of actual trees. However, the observers took perceived eye height up the tree explicitly by eye, measuring in a time-consuming fashion as if sequentially applying a ruler along the vertical extent of the tree trunk. The implication is that they could appreciate their eye height at the base of a tree (viewed on level ground), but had no immediate sense of tree height in terms of an eye-height or horizon ratio.

3. Mark and Warren perturbed estimates of size by raising the floor either underneath the judged object or underneath the observer, but they also might have done so by slanting the floor. An effect of a pitched surround on size judgments has been observed at the "Mystery Spot" in Santa Cruz, CA, as well as in the laboratory (Stoper & Bautista, 1992). This effect may well contribute to the altered perception of sizes obtained in an Ames room.

4. Studies on perceived eye level have revealed that pitched visual surroundings may strongly affect judgments of eye level (Stoper & Cohen, 1989, 1991; see also Matin & Fox, 1989), although information about the gravitational direction from the vestibular system and postural activity remains important for the stability and reliability of judgments (Stoper & Cohen, 1991).