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Perceiving Size in Events Via Kinematic Form

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Abstract

Traditional solutions to the problem of size perception have confounded size and distance perception. We investigated size perception using information that is independent of distance. As do the shapes of biological objects (Bingham, 1992), the forms of events vary with size. We investigated whether observers were able to use size specific variations in the kinematic forms of events as information about size. Observers judged the size of a ball in displays containing only kinematic information about size. This was accomplished by covarying object distance and actual size to produce equivalent image sizes for all objects and extents in the displays. Simulations were generated using dynamical models for planar events. Motions were confined to a plane parallel to the display screen. Mass density, friction, and elasticity were held constant over changes in size, simulating wooden balls. Observers were able to detect the increasing sizes of the equal image size balls. Mean size judgments exhibited a pattern predicted by a scaling factor in the equation of motion derived using similarity analysis.

Introduction

The textbook solution to the problem of size perception is to use the image size of an object and information about it's distance to derive the actual object size. This requires an ability to determine absolute distance, but most hypothesized sources of distance information specify only relative distance. Size-distance invariance theory confounds the problems of size and distance perception. Given the difficulty of the distance problem, seeking an independent solution to the problem of size perception might be useful.

Functional morphologists and scale engineers have discovered that the shape of objects change to preserve function over changes in scale (Baker, Westine & Dodge, 1973; Calder, 1984; Emori & Schuring, 1977; Hildebrand, Bramble, Liem & Wake, 1985; Thompson, 1961). Scale specific changes in form might provide a source of information about size that is independent of distance. Bingham (1992) has shown that observers are able to discriminate subtle variations in tree form and to use the information to judge the heights of trees. The variations in form were determined by two physically constrained scaling relations. This involved geometric form found in relatively static situations. Consideration of form variations in the context of events leads to forms of motion described via kinematics.

Bingham (1987a; b; 1991) has proposed that kinematic forms may provide visual information about both event identity and scale. In particular, Bingham (1991) suggested that forms in an optical phase space (optical positions vs. optical velocities) might provide visual information enabling observers to identify events. The problem is that spatial metrics are lost in the mapping from event kinematics to optical flows. For example, reference to optical velocities in terms of meters per second is meaningless. Further, the sensory apparatus exhibits strongly nonlinear characteristics in the detection of optical velocities. Ultimately, any scheme for the recovery of metric event velocities is bound to be unrealistic. Nevertheless, experimental evidence shows that observers are able to recognize particular types of events from apprehension of forms of motion. Accordingly, Bingham has argued that metric scaled information cannot be necessary and that ordinal scaling of velocity along continuous extents of optical phase trajectories should be sufficient to develop a taxonomy of qualitative properties used in event recognition. In fact, a level of scaling somewhere between ordinal and interval scaling is most likely.

Watson, Banks, von Hofsten, and Royden (in press) have proposed that visual perception of absolute size and distance might be based on the effects of gravity in constraining event motions and the resulting optical flows. They argue that their analysis is superior to earlier analyses by Chapman (1968) because theirs avoids a dependence on detection of optical accelerations. While the ability to detect optical velocity is well established, the ability to detect optical accelerations is uncertain (Regan,Kaufman, & Lincoln, 1986; Rosenbaum, 1975; Runeson, 1975; Schmerler, 1976; Todd, 1981; see the discussion in Bingham, 1991). In the Watson et al. analysis, distance is specified by a relation requiring detection of optical position, vertical velocity, the location of the focus of expansion, and time. Watson et al. avoid measures of optical accelerations by requiring metric information about both optical velocity at an instant and the time interval from the beginning of fall to the instant when velocity is measured. Both of these measures, however, are problematic. Accuracy in determining metric amounts of time is uncertain. Sufficient accuracy in this case is unlikely. Furthermore, measurement errors in detecting times and velocities would compound (Runeson, 1977). Most problematic, however, is the requirement for detection of metric valued velocities. As discussed above, this is inappropriate. Nevertheless, we should pursue the notion that gravity scales forms of motion in events in a way that can be used by the visual system to determine event scale.

An alternative approach is to expand the analysis from a determination of momentary metric values to spatio-temporally extended qualitative properties of optical trajectories.[1] Similarity methods are appropriate for a determination of the role of gravity in the mapping of trajectory forms into optical phase space. Before describing such an analysis , we describe an investigation as to whether observers can determine object size from motions. The only existing evidence that this might be possible is that produced by Johansson & Jansson (1967) in an unpublished study in which they asked observers to adjust a variable speed film projector.

Experiment 1: Judging in Inches with a Standard

To determine if optical phase space properties provide enough information for observers to accurately judge object sizes we created displays of several different events where all other types of information were eliminated. The image size of the object was the same in all displays. We achieved this by covarying simulated viewing distance and actual object size. If the optical phase space properties did not provide information about size then observers should not have been able to judge the sizes of the objects accurately.

Methods

Participants. Six undergraduates at Indiana University participated in the experiment for credit in an introductory psychology course. All participants had normal or corrected to normal vision.

Displays. Four types of events were used. A ball free falling and bouncing. A ball rolling down an inclined plane. A ball on the end of a string, acting as a pendulum, swinging downward, hitting and knocking over a block. Finally, a stack of four blocks with a ball on top all falling over and coming to rest on a ground surface. Each event was simulated at 5 different scales. In all displays the diameter of the ball was 1 cm on the screen. The simulated actual diameters of the balls ranged from 2.5 cm to 240 cm.

Simulations of planar events were generated using their dynamics and holding gravity, friction, elasticity, and mass density constant. The average frame rate across all of the events was 20 frames per second. Actual frame rates varied from 12 to 30 frames a second depending on the complexity of the displays.

To control for the possibility that observers might use event duration or peak velocity to produce judgments of object size, we manipulated these properties in the pendulum and inclined plane events independent of changes in size. Three levels of event duration (and peak velocity) were created in each of the five sizes of the two events by changing the incline of the surface and the length of the pendulum, for a total of 8 events. If event durations or peak velocities were being used, we expected events of identical sizes but different event durations (or peak velocities) to be judged differently.

Procedure. Before making judgments the observers were given a demonstration to ensure that they understood the situation being modeled. The demonstration involved two rubber playground balls of differing sizes. First, observers were shown how covariation of object size and distance can produce the same image size. The large ball was held approximately 6 feet from the observer while they adjusted the distance of the smaller ball so that it just occluded the larger ball. Second, observers witnessed examples of free fall events where the distances of fall were scaled to the size of the ball (that is, the larger ball was dropped from a greater height).

After this, observers sat facing a computer terminal and were asked to judge the actual diameter of the ball in each event display. They were allowed to view a display as many times as they felt necessary to make their judgment. The judgments were written in inches. Observers judged all 5 sizes of each event in a block of random ordered trials. Each of the 8 events were judged three times in different random ordered blocks. Preceding each of the first set of blocks, observers were shown a standard for that event. They were told the size of the ball in inches. The standard corresponded to the second largest event size. During the latter two trials the standard was only shown if the observer requested it. An experimental session lasted for 75 minutes.

Results and Discussion

As shown in Figure 1, mean judged size increased monotonically but nonlinearly with actual size in all events (save one). A repeated measures analysis of variance (ANOVA) was performed on size judgments with event type, actual size, and trial as factors. The main effects for event type and size were significant, $F(7, 35)=3.88$, $p<.005$ and $F(5,25)=25.36$, $p<.001$, as was their interaction, $F(35,175)=3.30$, $p<.001$. Simple effects tests revealed that within each event type the sizes were judged differently, $p<.001$, in all cases. Simple effects also showed that the judgments did not differ significantly across the 8 event types at the lowest and highest size levels, but that they did at the other size levels. Observers regularly overestimated the smaller sizes and underestimated the larger sizes resulting in a curved pattern of judgments crossing a line representing absolute precision near the value of the standard.

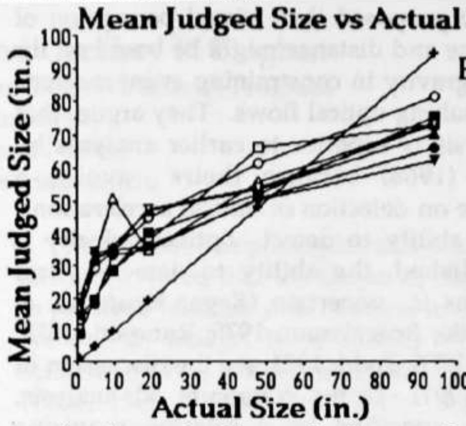


Figure 1.

As shown in Figure 2, the manipulation of event duration for the inclined plane and pendulum events revealed that judgments of size were independent of event durations or peak velocities.

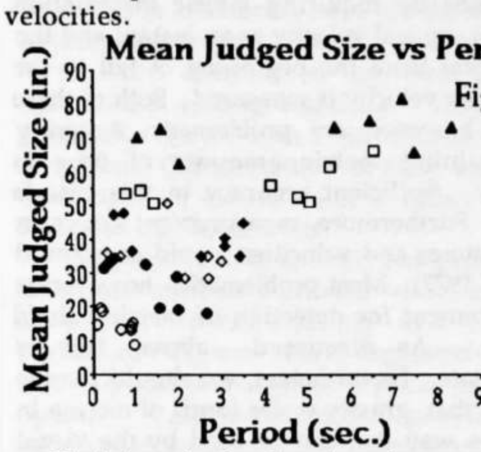


Figure 2.

Variations in the duration of an event within a size level (for instance, the 3 different inclinations of the slope for a given event size) did not prevent observers from correctly grouping objects of the same sizes. Objects of equal size were judged as similar despite different event durations both within a type of event and across the two different types of events. Because peak velocity covaried with event duration, we wished to conclude that event duration and peak velocity were not used to judge object size. However, it was possible that the use of standard trials suppressed the tendency for judgments to reflect event durations. All of event displays were calibrated by the standards at the second largest size level. The next experiment was performed to investigate this possibility.

Experiment 2: Judgments without Numbers or a Standard

To avoid the use of a standard display, we changed the method used by observers to express their judgments. Rather than writing a value in inches, we instructed observers to express ball size using hand span. The observers adjusted the distance between their hands making motions as if they were grasping the ball between their hands. We witnessed several of the observers from the first experiment doing this to estimate size in inches. This measure would avoid the use of numbers requiring an extrinsic system of units and the use of a standard.

Methods

Participants. Five undergraduates at Indiana University participated in the experiment for credit in an introductory psychology course. All participants had normal or corrected to normal vision.

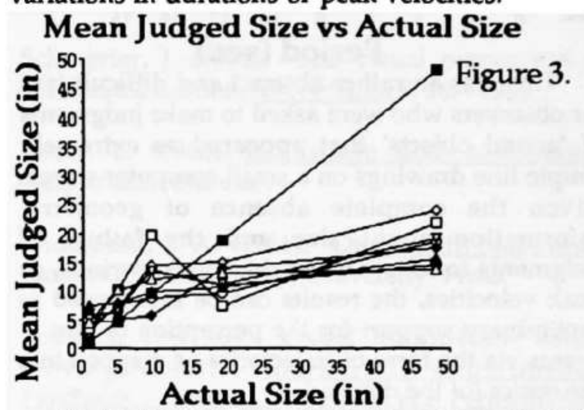
Displays . The same set of displays were used as in Experiment 1 with the exclusion of the largest event size. All other aspects of the displays remained the same.

Procedure. Observers were instructed to place their hands as if they meant to hold the ball shown in the display. The distance between their hands was measured by the experimenter using a standard tape measure. Observers never saw the numbers on the tape. As before, observers were not given feedback on their performance.

No standard displays were shown to the observers. Because judgments across trials in Experiment 1 were not different, we decided to shorten the total session time by collecting only a single judgment of each event display. This was done also to compensate for the extra time required to make the hand span measurements. Observers were first shown the entire set of displays in a random order. No judgments were expressed at this point. Following this, observers viewed and judged the displays in a different random order. An experimental session lasted 1 hr.

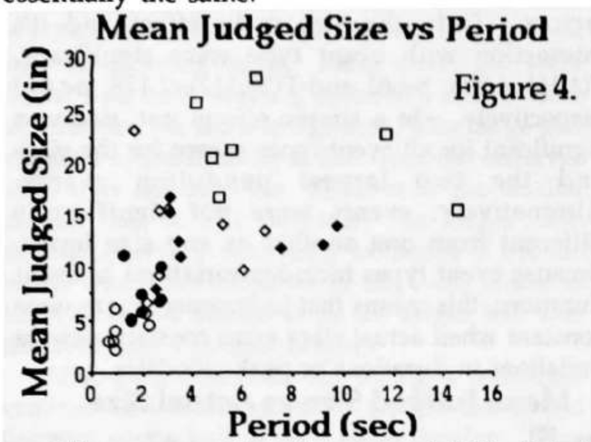
Results and Discussion

Once again, mean judgments increased nonlinearly with actual size for all event types. A repeated measures ANOVA was performed on size judgments with event type and actual size as factors. Only the size main effect and it's interaction with event type were significant, $F(4,16)=4.805$, $p<.01$ and $F(28,112)=2.178$, $p<.003$ respectively. In a simple effects test, size was significant for all event types except for the stack and the two largest pendulum events. Alternatively, events were not significantly different from one another at any size levels. Because event types includes variations in event durations, this means that judgments of size were constant when actual sizes were constant despite variations in durations or peak velocities.



As in Experiment 1, there was a curved pattern to the mean judgments with overestimation of the smaller sizes and underestimation of the larger sizes. However, in this experiment, judged sizes were lower overall, with less overestimation of smaller sizes and greater underestimation of larger sizes. Mean judgments crossed the line marking absolute precision at 10-15 in actual size. The ceiling on mean judgments was not much above this value which corresponded to the size of the largest ball used in the demonstration preceding the experiment. Such demonstrations are known to produce "transfer effects" affecting the values subsequently used by observers in making magnitude estimations (Poulton, 1989).

The main question addressed in this experiment was whether recalibration via standard trials prevented judgments from following variations in event durations, periods, or peak velocities. The current study was performed without standards. Event durations were manipulated over events of constant size for the inclined plane and pendulum events. The results appear in Figure 4 and should be compared to those from Experiment 1 as shown in Figure 2. The results in the two experiments were essentially the same.



This was an rather abstract and difficult task for observers who were asked to make judgments of 'actual objects' that appeared as extremely simple line drawings on a small computer screen. Given the complete absence of geometric information about size and the failure of judgments to follow event durations, periods, or peak velocities, the results can be interpreted as preliminary support for the perception of size in events via the form of trajectories as mapped into the optics (of the display).

General Discussion

What qualitative properties of event trajectories might observers have used to judge event scale? We examined the optical phase portraits for all of the events and found a form common to all of the trajectories. All of the trajectories contain segments that were parabolic. In the free fall and bounce, inclined plane, and pendulum events the trajectories were entirely parabolic or nearly so. Because of repeated collisions in the falling stack, only portions of the trajectories were parabolic. The parabolic forms reflect gravitation and (constrained) free fall.

We performed a similarity analysis focusing on free fall to determine whether mapping into the optics distorted the otherwise self-similar forms in a way specific to the scale.[2] Thus the relevant scale transformation was the mapping into optics, performed by dividing all quantities by the viewing distance. By setting the optical height of fall to 1 (that is, the initial height condition in the display), we could perform this transformation by using the actual initial height (ho) to divide instead. The question in performing the similarity analysis was whether, after the transformation had been performed on the equation, the original form of the equation could be recovered in the scale transformed variables (Szücs, 1980). If so, then the scale transformation should be 'benevolent', meaning that the trajectory forms are preserved. If not, then a distortion of the trajectory forms should result directly from the scale transformation. An accessory factor may be isolated which represents the scale specific form of the distortion. Using the equation describing the free fall trajectory in phase space (that is, velocity as a function of position) and ignoring air resistance, we performed the analysis as follows:

Equation of motion for Free Fall

$$\dot{y} = g[2(y-h_o)]^{1/2}$$

Transformation into Optics

$$h_o' = h_o/h_o \qquad y' = y/h_o \qquad \dot{y}' = \dot{y}/h_o$$

Equation in Optical Terms

$$\dot{y}' = g[2(y'-h_o')]^{1/2}\,[h_o]^{1/2}$$

We found that the mapping from event kinematics to optic flows yields a distortion that scales the trajectories by the reciprocal of the initial height to the square root. The square root in the scaling factor accounts for the curvature of the mean judgments. This scaling factor describes the decreasing resolution exhibited in judgments as the object size became larger. Thus, the form of the judgment curves reflected the form of the function determining the information made available via the simple models used to generate these displays.

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Endnotes

1. Detecting the form of trajectories in optical phase space does not require the detection of optical accelerations. Acceleration can be derived from the slope of a trajectory in phase space, but the rate of change of velocity with respect to position is not the same as acceleration. See Bingham (1991) for discussion.

2. The analysis generalizes directly to the inclined plane and pendulum events