Journal of Experimental Psychology:
Human Perception and Performance
2006, Vol. 32, No. 6, 1398–1404

0096-1523/06/$12.00 DOI: 10.1037/0096-1523.32.6.1398

Size Constancy in Infants: 4-Month-Olds' Responses to Physical Versus Retinal Image Size

Carl E. Granrud
University of Northern Colorado

This study tested whether 4-month-old infants respond primarily to objects' physical or retinal image sizes. In the study's main experiment, infants were habituated to either a 6-cm-diameter disk at a distance of 18 cm or a 10-cm disk at 50 cm. They were then given 2 test trials in which the 6- and 10-cm disks were presented side by side at a distance of 30 cm. For each infant, one test object had a novel physical size but a familiar retinal image size, and the other had a familiar physical size but a novel retinal image size. The infants exhibited a significant looking preference for the object that had a novel physical size. A preliminary experiment found that 4-month-olds' looking preferences are based on novelty, not familiarity, under the conditions of this study. Given this finding, the results suggest that 4-month-old infants attend and respond primarily to physical size, not to retinal image size.

Keywords: size constancy, size perception, object perception, infancy, perceptual development

When a solid object is viewed, changes in viewing distance cause changes in the object's retinal image size. Yet, adults typically perceive that the object maintains a constant size despite almost continuous change in its retinal image size caused by movements of the observer or object (i.e., they exhibit size constancy). Researchers have asked, since early in the history of infant perception research, whether infants, like adults, perceive stable objects that maintain constant sizes or whether infants see objects as changing in size with changes in viewing distance. Several studies have found evidence that 4- to 6-month-old and newborn infants perceive objects' physical sizes across changes in distance and retinal image size (Day & McKenzie, 1981; McKenzie, Tootell, & Day, 1980; Slater, Mattock, & Brown, 1990). However, studies have also found that infants respond to retinal image size (e.g., Slater et al., 1990), and it has remained unknown whether infants' perceptions correspond primarily to objects' constant physical sizes or to their changing retinal image sizes. On the basis of the research published to date, it is clear that infants can perceive and respond to objects' physical sizes, but it is possible that, to infants, retinal image size is more salient than physical size.

This point can be illustrated by considering Day and McKenzie's (1981) study on size constancy in 4-month-old infants. Infants in their study viewed an object (a realistic model of a human head) that approached and receded until a habituation criterion was reached. Test trials were then conducted in which the infants viewed, one at a time, the object that had been seen during habituation and a novel object, which differed from the habituation object in size only. These objects approached and receded, as in the habituation trials, and both objects' distances and retinal image sizes fell within the range of those seen during habituation. The infants remained habituated to the familiar object and dishabituated to the novel-sized object. Because retinal image size was controlled, discrimination of the test objects must have been based on physical size. Day and McKenzie's results, therefore, demonstrated that 4-month-old infants can achieve some degree of size constancy.

Infants in the Day and McKenzie (1981) study were shown changing distances and retinal image sizes throughout the habituation trials. This was a key feature of the study. It was done to desensitize infants to changes in distance and retinal image size to maximize the likelihood that, in the test trials, the infants would respond to the objects' physical sizes and ignore changes in distance and retinal image size. The 4-month-old infants in Day and McKenzie's study responded to physical size after desensitization to changes in retinal image size. But how would 4-month-olds respond if they were not desensitized to retinal image size? Infants at this age might spontaneously respond to objects' physical sizes, but it is possible that they would respond to retinal image size rather than physical size if no prior desensitization had been done.

The Slater et al. (1990) study on size constancy in newborn infants also used a desensitization method. Their initial experiment asked whether newborns exhibit looking preferences when viewing two different-sized objects (patterned black-and-white cubes), presented side by side at varying distances, and whether looking preferences are based on physical or retinal image size. The infants exhibited consistent looking preferences, and these preferences were based on retinal image size exclusively. In their second experiment, Slater et al. desensitized infants to retinal image size during a series of habituation trials by presenting an object (a cube) at varying distances. In subsequent test trials, the object that had been seen during habituation was presented with a novel-sized object (a cube that differed from the habituation object in size only). The two test objects were placed at different distances, and their retinal image sizes were matched. The infants looked pref-

I gratefully acknowledge Denis Burnham, who brought to my attention the gap in the literature that this study addresses, and Margot Osofsky and Sue Lammie, who helped with data collection.

Correspondence concerning this article should be addressed to Carl E. Granrud, School of Psychological Sciences, Campus Box 94, University of Northern Colorado, Greeley, CO 80639. E-mail: carl.granrud@unco.edu

erentially at the novel-sized test object, thus exhibiting some degree of size constancy. Although the infants responded to physical size after desensitization to retinal image size, the first experiment in the Slater et al. study suggested that retinal image size is highly salient to newborn infants; their study left open the possibility that infants would respond primarily to objects' retinal image sizes, not to their physical sizes, if no desensitization had been done.

McKenzie et al. (1980) investigated size constancy in 4- and 6-month-old infants without using a desensitization procedure. Infants in their study were habituated to either a large or small object (models of human heads). There were four habituation conditions. During habituation, infants in the "control" (Co) condition saw the large object at a distance of 60 cm, those in the size constancy (SC) condition saw the large object at 30 cm, infants in the "distance" (Di) condition saw the small object at 60 cm, and those in the "visual angle" (VA) condition saw the small object at 30 cm. After habituation occurred, all of the infants were given a test trial with the large object at a distance of 60 cm. Six-month-olds in the Co and SC conditions remained habituated during the test trial, whereas 6-month-olds in the Di and VA conditions dishabituated. The 6-month-olds, therefore, exhibited size constancy. These infants generalized habituation based on physical size across a change in retinal image size (in the SC condition), and they discriminated different-sized objects that projected equal retinal image sizes (in the VA condition). The 4-month-old infants did not show evidence of size constancy.

The McKenzie et al. (1980) study provided suggestive evidence that physical size may be more salient than retinal image size for 6-month-old infants. These infants responded to a change in physical size when retinal image size stayed constant (in the VA condition) but did not respond to a change in retinal image size when physical size stayed constant (in the SC condition). It should be noted, however, that the infants were not shown equivalent changes in physical and retinal image size in the two conditions that tested for size constancy (the VA and SC conditions). When physical size changed (in the VA condition), size increased from the habituation trials to the test trial, but when retinal image size changed (in the SC condition), size decreased from the habituation trials to the test trial. (In the Di condition, both physical and retinal image size increased; as a result, responses to physical and retinal size were not compared in this condition.) It is possible that the infants noticed and responded to the change in physical size in the VA condition (by dishabituating) but did not respond to the change in retinal image size in the SC condition (remaining habituated), not because physical size is more salient than retinal image size but because size increases are more salient than size decreases. Because changes in physical and retinal image size were not equivalent, the McKenzie et al. study did not make a direct comparison of infants' responses to physical and retinal image size. To determine which is more salient to infants, one would need to observe infants' responses to comparable changes in physical and retinal image size.

The above comments are not meant as criticisms of the Day and McKenzie (1981), McKenzie et al. (1980), or Slater et al. (1990) studies. These studies used innovative methods, incorporated rigorous control over extraneous variables, and made important contributions to the literature on infant perception by finding evidence of size constancy in 6-month-old, 4-month-old, and newborn infants. Furthermore, these studies sought evidence that infants could perceive the physical sizes of objects; they were not designed to compare the relative salience of physical and retinal image size. It is important, nevertheless, to recognize the limitations in what can be concluded on the basis of these studies. They found that infants exhibit some degree of size constancy, but they did not answer the basic question of whether infants' perceptions correspond primarily to objects' constant physical sizes or to the changing sizes of retinal images.

One additional study, by Bower (1965), should be mentioned. In the Bower study, 6- to 9-week-old infants were conditioned to make head-turn responses when viewing a cube, with 30-cm sides, that was presented at a distance of 1 m. The infants exhibited greater generalization of the conditioned response to a 30-cm cube presented at 3 m than to a 90-cm cube at 3 m. Thus, generalization of the conditioned response between the training and test stimuli was based more on similarity in physical size than on similarity in retinal image size. As in the McKenzie et al. (1980) study, however, changes in physical and retinal image size were not equivalent. In the two conditions that tested for size constancy (the 30- and 90-cm cubes at 3 m), the change in physical size from the training phase to the test phase involved a size increase, whereas the change in retinal image size involved a size decrease. Consequently, the Bower study did not make a direct comparison of infants' responses to physical and retinal image size. Furthermore, the Bower study was not reported at the level of detail that is usually seen in a published research report. As a result, the study's findings are difficult to evaluate, and conclusions based on Bower's study must be drawn cautiously. The object sizes, distances, and visual angles used in the Day and McKenzie (1981), McKenzie et al. (1980), Slater et al. (1990), and Bower (1965) studies are summarized in Table 1.

The present study tested whether 4-month-old infants respond primarily to objects' physical sizes or retinal image sizes. In the study's main experiment (Experiment 2), infants were habituated to either a 6-cm diameter disk at a distance of 18 cm or a 10-cm disk at a distance of 50 cm. They were then given two test trials in which the 6- and 10-cm disks were presented side by side at a distance of 30 cm. Looking behavior was observed to determine whether the infants exhibited a looking preference in the test trials. For each infant, one test object had a novel physical size but a familiar retinal image size, and the other had a familiar physical size but a novel retinal image size. This design allowed a direct comparison of infants' responses to physical and retinal image size. But before this experiment was conducted, a preliminary experiment (Experiment 1) was needed to determine whether infants exhibited a preference for novel-sized or familiar-sized objects under the conditions of this study.

Experiment 1

Experiment 1 consisted of a series of habituation trials followed by two test trials. During the habituation trials, one group of infants, Group A, viewed a circular object that was 6 cm in diameter, and another, Group B, a circular object that was 10 cm in diameter. Both habituation objects were presented at a distance of 30 cm. In the test trials, both groups viewed the 6- and 10-cm objects, positioned side by side, at a distance of 30 cm. The objects' left–right positions were alternated between the two test

Table 1
Summary of Object Sizes, Viewing Distances, and Visual Angles in Four Studies

Trials	Object size	Distance	Visual angle	Presentation
		Day & McKenzie (1981)		
Habituation	13 cm	30–236 cm	3–24°	Each infant viewed one object that moved in depth through a range of 50 cm from varying starting points in each trial.
	26 cm	30–236 cm	6–47°	
Test	13 cm	55–155 cm	5–13°	Each infant viewed both test objects, one at a time. Each object moved in depth through a range of 50 cm from a variable starting point in each trial.
	26 cm	55–155 cm	10–27°	
		McKenzie, Tootell & Day (1980): Experiment 1		
Habituation				Each infant viewed one stationary object during habituation trials.
Co condition	26 cm	60 cm	24°	
SC condition	26 cm	30 cm	47°	
Di condition	13 cm	60 cm	12°	
VA condition	13 cm	30 cm	24°	
Test	26 cm	60 cm	24°	Each infant viewed one stationary object in the test trial.
		Slater, Mattock, & Brown (1990): Experiment 2		
Habituation	5.1 cm	23–69 cm	4.2–12.7°	Each infant viewed one stationary object presented at varying distances.
	10.2 cm	23–69 cm	8.5–25.0°	
Test	5.1 cm	30.5 cm	9.6°	Each infant viewed two stationary objects presented side by side at fixed distances.
	10.2 cm	61 cm	9.6°	
		Bower (1965)		
Training	30 cm	1 m	17.1°	Infants were trained to make conditioned head turns when the training object was visible.
Test	30 cm	1 m	17.1°	Each infant viewed one of the four test objects and head-turn responses were observed.
	30 cm	3 m	5.7°	
	90 cm	1 m	48.5°	
	90 cm	3 m	17.1°	

Note. Exact object sizes were not reported in the Day & McKenzie (1981) and McKenzie et al. (1980) articles. The stimulus objects were described as a "life-size" model of a female human head and a model of a head reduced in size by half. The object sizes and visual angles (which refer to head height) listed in Table 1 are approximations that were inferred from distance and approximate visual angle information provided in the McKenzie et al. (1980) article. Co = control; SC = size constancy; Di = distance; VA = visual angle.

trials. Time spent fixating each object was recorded, and each test trial continued until 10 s of total looking time had accumulated. The goal of this experiment was to determine whether 4-month-old infants would exhibit a looking preference in the test trials and, if so, whether a novelty or familiarity preference was exhibited. The objects' sizes, distances, and visual angles in Experiment 1 are summarized in Table 2.

Throughout the habituation and test trials, the objects moved back and forth along a straight, horizontal path perpendicular to the infants' line of sight. Movement was introduced on the basis of results of a pilot experiment in which 8 infants were tested with stationary objects. These infants did not appear to be engaged by the objects, exhibited short looking times during the habituation trials, and often became fussy. Movement engaged the infants' attention more effectively, and the infants were less likely to become fussy while viewing the moving objects.

Because distance was not varied in Experiment 1, this experiment was not a test of size constancy. However, investigating the nature of infants' looking preferences under the conditions of this study was an important first step in the study that was necessary for interpreting the results of Experiment 2, which did test size constancy.

Method

Participants. Infant research participants were recruited from birth announcements published in local newspapers. Each infant was brought to the laboratory by a parent, who gave written informed consent.

The sample in Experiment 1 included 16 infants: 10 girls and 6 boys, with a mean age of 121.0 days and an age range of 116–126 days. Ten additional infants were tested but excluded from the sample. Three became too fussy to complete the experiment, 2 completed the experiment but were judged as too fussy or inattentive to be included in the sample by an observer who viewed their videotaped test sessions, 1 did not meet the habituation criterion, and 4 were excluded because of equipment failure or experimenter error.

Apparatus. Four stimulus objects were used in Experiment 1.These objects were white disks decorated with red "smiling face" features, modeled after those used by Fantz (1961). The four stimuli were matte-finished, photographic reproductions of one original stimulus. These stimuli varied only in size. The photographs were affixed to rigid plastic disks, which measured 2 mm in thickness. Two objects were used in the habit-

Table 2
Object Sizes, Viewing Distances, and Visual Angles in Experiments 1 and 2

Trials	Object size	Distance	Visual angle	Presentation
		Experiment 1		
Habituation	6 cm (Group A)	30 cm	11.4°	Each infant viewed one object during habituation:
	10 cm (Group B)	30 cm	18.9°	either the 6- or 10-cm disc.
Test	6 cm	30 cm	11.4°	Each infant viewed the two test objects presented
	10 cm	30 cm	18.9°	side by side.
		Experiment 2		
Habituation	6 cm (Group A)	18 cm	18.9°	Each infant viewed one object during habituation:
	10 cm (Group B)	50 cm	11.4°	either the 6- or 10-cm disc.
Test	6 cm	30 cm	11.4°	Each infant viewed the two test objects presented
	10 cm	30 cm	18.9°	side by side.

uation phase of the experiment: One had a diameter of 6 cm, and the other had a diameter of 10 cm. Two additional objects, identical to those used during habituation, were presented in the test trials. During the habituation trials, one object (either the 6- or 10-cm object) was presented directly in front of the infant, with its front surface oriented vertically, at a distance of 30 cm from the infant's eyes. During the test trials, the 6- and 10-cm test objects were presented side by side, with their centers separated by 20 cm, at a distance of 30 cm from the infant's eyes to the plane of the objects' front surfaces.

Throughout the experiment, the infant sat in an infant car seat, which was attached to a 61-cm-high platform, within a three-sided enclosure. The area within the enclosure was illuminated by fluorescent ceiling lights. The enclosure's 165 (height) × 70 (width) cm gray central wall formed the background for the stimulus objects. Its two 120 × 140 cm gray side walls blocked the laboratory room from the infant's view. A door in each side wall could be opened to position the stimulus objects. A colorfully patterned curtain, mounted on a rod between the two side walls, could be lowered to occlude the stimulus objects between trials. Each object was suspended in front of the background surface by a horizontal rod that protruded from the background surface, along a line parallel to the infant's line of sight. The objects occluded the rods from the infant's viewpoint. One end of the rod attached to the back of the object; the other end attached to a carriage mechanism that rode on a track behind the background surface.

An experimenter moved the stimulus objects by sliding the carriage along the track. A 1 × 30 cm horizontal slot in the background allowed this movement. During the habituation and test trials, the objects were moved back and forth along a horizontal path perpendicular to the infant's line of sight. The objects' range of movement was chosen randomly for each trial from the whole-number values of 2–8 cm. The positions of two rubber bumpers, attached to the track, were adjusted to limit the objects' range of movement. Range of movement was varied to ensure that there was no constant relationship between any stimulus object's physical size and the extent of its physical motion, or between retinal image size and extent of retinal motion, across the habituation and test trials. This was done to control for the possibility that, in Experiment 2, infants' looking behavior might be influenced by the detection of such relationships.

A video camera recorded the infant through an aperture in the center of the background surface, 10 cm above the horizontal line that bisected the stimulus objects. The infant and stimulus objects were visible on a video monitor linked to the camera. During each trial, an experimenter viewed the infant on the monitor and recorded the infant's fixation times using a timing device connected to a desktop computer. During the habituation trials, the experimenter pressed a button on the timing device while the infant fixated the object and released the button when the infant looked away from the object. The computer recorded the total fixation time accumulated during each habituation trial and signaled, with tones, when each habitation trial was completed and when the habituation criterion was reached. During the test trials, the experimenter pressed one button on the timing device while the infant fixated one stimulus object and pressed another button while the infant fixated the other object. The computer recorded the infant's cumulative fixation time for each object during each test trial and signaled, with a tone, when each trial was completed.

Two experimenters conducted the experiment. Experimenter 1 viewed the video monitor, recorded the infants' looking behavior, and positioned the stimulus objects between trials. Experimenter 2 moved the objects and controlled the curtain. Throughout the experiment, Experimenter 2 was kept unaware of the test objects' left–right positions and the condition to which each infant had been assigned. This was done to ensure that experimenter bias could not influence the infants' looking behavior based on how the objects were moved.

Procedure. The experiment consisted of a series of habituation trials followed by two test trials. The infants were assigned to two groups, A and B (with 8 infants per group), in counterbalanced order. During the habituation trials, Group A viewed the 6-cm object and Group B viewed the 10-cm object. Both groups viewed the 6- and 10-cm objects, presented side by side, during the test trials.

Before testing began, the infant was seated in the car seat, distance was measured between the infant's eyes, and an 8-cm diameter, black and white bull's-eye stimulus was placed at the location of the habituation object, and the seat's position on the platform was adjusted to place the infant at the correct viewing distance. The curtain was then lowered, and the habituation object was put into position. Experimenter 2 initiated the first habituation trial by raising the curtain to reveal the stimulus object. Each habituation trial began when the infant first fixated the object and continued until the infant looked away from the object for 2 continuous seconds, or until 60 s of total fixation time had accumulated. The experimenter then lowered the curtain to terminate the trial. After an intertrial interval of approximately 4 s, Experimenter 2 raised the curtain to initiate a new trial, which followed the same procedure. These trials continued until the habituation criterion was reached or until 10 trials had been completed. The habituation criterion was two consecutive trials whose combined total fixation time was 50% or less than the combined total fixation time of the first two trials. This criterion had one exception. If the infant exhibited less than 4 s of total fixation time in the first habituation trial, that trial was disregarded, and the first trial with 4 or more seconds of fixation was treated as the first trial for computing the habituation criterion.

Following the habituation trials, Experimenter 1 positioned the stimulus objects for the first test trial. In the first test trial, the novel-sized object was presented on the left for half of the infants in each group and on the right for the other half. After a 10-s interval separating the habituation and test trials, Experimenter 2 raised the curtain to initiate the first test trial. The trial began when the infant first fixated one of the objects, and continued until 10 s of total fixation time (for both objects combined) had accumulated. Experimenter 2 then lowered the curtain to terminate the trial, and Experimenter 1 changed the objects' left–right positions. After a 10-s intertrial interval, the curtain was raised to initiate the second test trial, which followed the same procedure.

The infants' test-trial fixation times were scored live and from the videotaped record of the experiment. In the data scored live, exactly 10 s of total looking time was recorded for each test trial. A maximum of 10 s of looking time per test trial could be recorded for the data scored from videotape, but no minimum looking time was imposed on these data. As a result, test-trial total looking times could be less than 10 s in the data scored from videotape. Because experimenter bias could potentially influence the data that were scored live, the test-trial data scored from videotape were used in all analyses. To avoid experimenter bias, the observer who scored fixation times from the videotape was kept unaware of which object was novel for each infant. The live data were used to measure interobserver reliability. A Pearson's r correlation was computed between the values recorded live and from videotape for percentage of looking time devoted to the novel test object (for the two test trials combined). The correlation between the values recorded live and from videotape was $r = .98$, indicating a high degree of interobserver reliability.

Infants were excluded from the sample if they met any of three exclusion criteria. First, an infant was excluded if, in the judgment of Experimenter 1 or the parent, the infant became too fussy to complete the experiment. Second, an infant was excluded if the observer who scored the infant's videotaped test session judged the infant to be too fussy or inattentive to provide valid data. This judgment was made blind to the condition to which the infant had been assigned, to avoid the possibility of experimenter bias influencing this decision. Third, an infant was excluded if the habituation criterion was not reached in 10 habituation trials.

Results and Discussion

The infants completed a mean of 5.69 habituation trials (SD = 1.89). Mean looking times were 32.81 s (SD = 20.79) in the first habituation trial and 8.17 (SD = 8.10) s in the last habituation trial. The mean total looking time in each test trial was 10.0 s (SD = 0). Table 3 shows the mean percentage of total looking time that was spent fixating the novel-sized object in each test trial. One-sample t tests were conducted to compare the mean percentages, calculated from all 16 infants, to 50%. The infants looked preferentially at the novel-sized object in Trial 1. Their mean of 66.14% was significantly greater than 50%, $t(15) = 2.58$, $p < .05$. The infants did not exhibit a significant looking preference in Trial 2, $t(15) = 0.45$, $p > .05$.

In the first test trial, the infants looked significantly longer at the novel-sized object than at the familiar-sized object. No looking preference was exhibited in the second test trial. This result is not surprising. After the objects had been seen in Trial 1, neither object was novel in Trial 2. Thus, a looking preference based on novelty might be expected to disappear after the first test trial. For the purpose of this study, however, it was not important to determine why no looking preference occurred in Trial 2. The goal of Experiment 1 was to determine whether 4-month-old infants would exhibit a looking preference under the conditions of this study, and the infants in this experiment exhibited a clear novelty preference in the first test trial.

Table 3
Mean Percentage of Looking Time Spent Fixating the Novel-Sized Object in Experiment 1

		Trial 1		Trial 2	
Group	N	M	SD	M	SD
A	8	77.33	19.08	60.31	24.71
B	8	54.95	26.24	40.37	32.68
A + B	16	66.14	25.00	50.34	29.82

In addition to exhibiting a looking preference for the novel-sized test object, the infants looked preferentially at the larger test object. In each test trial, the infants spent approximately 60% of their looking time fixating the larger object (a significant effect in each trial). This result is consistent with previous findings that infants attend more to larger objects than to smaller objects (e.g., Day & McKenzie, 1981). The infants' preferences for the novel test object and for the larger test object apparently worked together to amplify the looking preference exhibited by Group A but worked against each other to attenuate the looking preference exhibited by Group B. The infants' looking preference for the larger object is worth noting because it explains the different results obtained from Groups A and B. But the more important finding of Experiment 1 was that the infants' looking preference for the novel-sized object was sufficiently robust that it was not obscured by their concomitant preference for the larger object.

The results of Experiment 1 had clear implications for Experiment 2. First, with the data from both groups combined, the infants in Experiment 2 were expected to exhibit a significant looking preference for the test object that they perceived to be novel. Second, this looking preference was expected in the first test trial only.

Experiment 2

Experiment 2 was similar to Experiment 1. But, in Experiment 2, we changed the viewing distance between the habituation and test trials to conduct a test of size constancy. Infants in Group A were habituated to the 6-cm object at a distance of 18 cm, and infants in Group B were habituated to the 10-cm object at a distance of 50 cm. Two test trials were then conducted in which both groups viewed the 6- and 10-cm objects, presented side by side, at a distance of 30 cm. For each infant, one test object had the same physical size as the object seen during habituation but had a novel retinal image size, and the other object had a novel physical size but had the same retinal image size that was seen during habituation. The results of Experiment 1 indicated that 4-month-old infants exhibit a looking preference for novel size under the conditions of this study. A looking preference for the object with a novel physical size would, therefore, indicate that the infants responded primarily to physical size, whereas a looking preference for the object with a novel retinal image size would indicate that the infants responded primarily to retinal image size.

Method

Participants. The sample in Experiment 2 included 16 infants: 8 females and 8 males, with a mean age of 120.1 days and an age range of 117–126 days. Nine additional infants were tested but excluded from the sample. Four became too fussy to complete the experiment, 4 completed the experiment but were excluded on the basis of the judgment of the observer who viewed their videotaped test sessions, and 1 did not reach the habituation criterion.

Apparatus. Experiment 2 used the same apparatus that was used in Experiment 1. There was only one difference between Experiments 1 and 2: In Experiment 2, viewing distance was changed between the habituation and test trials. The 6-cm habituation object seen by Group A was presented at a distance of 18 cm, and subtended 18.4° of visual angle. The 10-cm habituation object seen by Group B was presented at a distance of 50 cm and subtended 11.3° of visual angle. During the test trials, the 6- and 10-cm objects were presented side by side at a distance of 30 cm for both groups. These objects subtended 11.3° and 18.4° of visual angle, respectively.

Procedure. Experiment 2 followed the same procedure that was used in Experiment 1. As in Experiment 1, the data recorded from videotape were used in all analyses, and the live data were used to measure interobserver reliability. A Pearson's r correlation was computed between the values scored live and from videotape for percentage of test-trial looking time devoted to the physically novel object. A correlation of $r = .96$ was obtained, indicating a high degree of interobserver reliability.

Results and Discussion

The infants completed a mean of 6.31 ($SD = 2.15$) habituation trials. Mean looking times were 23.83 s ($SD = 19.81$) in the first habituation trial and 5.17 s ($SD = 3.21$) in the last habituation trial. Mean total looking times in the test trials were 9.97 s ($SD = 0.12$) for Trial 1 and 10.0 s ($SD = 0$) for Trial 2. Table 4 shows the mean percentage of looking time in each test trial that the infants spent fixating the object that had a novel physical size. One-sample t tests were conducted to compare the mean percentages, computed from all 16 infants, to 50%. In Trial 1, the infants exhibited a significant looking preference for the test object that had a novel physical size. Their mean of 65.19% was significantly greater than 50%, $t(15) = 3.36$, $p < .01$. The infants did not exhibit a significant looking preference in Trial 2, $t(15) = -0.10$, $p > .05$.

As in Experiment 1, the infants exhibited a looking preference in the first test trial only, and they looked preferentially at the larger test object, devoting approximately 60% of their Trial 1 looking time to the larger object. Although worth noting, these results are not important regarding the main purpose of the study.

The key result of Experiment 2 was the infants' looking preference for the test object that had a novel physical size. This result indicates that the infants achieved some degree of size constancy. In the first test trial, the infants apparently recognized the object that had been seen during habituation, despite a change in its distance and retinal image size, and perceived the novel physical size of the other object, despite its familiar retinal image size. The results, therefore, confirm Day and McKenzie's (1981) finding that 4-month-old infants can perceive an object's physical size across a change in distance and retinal image size. The results also suggest that physical size is more salient than retinal image size to 4-month-old infants. Experiment 1 found a looking preference for novel size. Given this finding, the looking preference found in Experiment 2 suggests that the infants perceived the object that had a new physical size as more novel than the object that had a new retinal image size. It, therefore, appears that the infants in Experiment 2 responded primarily to the objects' physical sizes.

Table 4
Mean Percentage of Looking Time Spent Fixating the Physically Novel Object in Experiment 2

		Trial 1		Trial 2	
Group	*N*	*M*	*SD*	*M*	*SD*
A	8	75.47	15.72	49.41	41.49
B	8	54.92	14.62	49.02	24.13
A + B	16	65.19	18.10	49.22	32.79

Two important features of Experiment 2 are worth noting. First, the infants saw comparable changes in physical and retinal image size between the habituation and test trials. For Group A, the novel physical object was 67% larger than the habituation object, and the novel retinal image was approximately 40% smaller than that seen during habituation. For Group B, the novel physical object was 40% smaller than the habituation object, and the novel retinal image was approximately 67% larger than that seen during habituation. Averaged across the two groups, changes in physical and retinal image size were equivalent.

As noted earlier, the McKenzie et al. (1980) and Bower (1965) studies did not present equivalent changes in physical and retinal image. The infants in these studies responded to changes in physical size and ignored changes in retinal image size. However, in the conditions that tested size constancy in these studies, physical size always increased and retinal image size always decreased between the habituation, or training, trials and the test trials. It is possible that the infants noticed and responded to size increases and ignored size decreases. As a result, these studies did not provide evidence that infants attend more to physical size than to retinal image size. This type of explanation cannot account for results of the present study. If the infants responded to size increases and not to physical size, both groups would be expected to look preferentially at the larger test object (on the basis of an increase in physical size for Group A and an increase in retinal image size for Group B), and with the data from both groups combined, the infants would be expected to spend 50% of their total looking time fixating the physically novel test object.

A second important feature of the experiment was that no desensitization was done during the habituation trials. In the habituation phases of the Day and McKenzie (1981) and Slater et al. (1990) studies, infants were desensitized to changes in retinal image size to maximize the chances that they would respond to physical size and ignore retinal image size during the test trials. In the test trials of Experiment 2, physical and retinal image size were put in direct competition for the infants' attention, and the infants responded to physical size. This response was spontaneous and was not influenced by prior desensitization to retinal image size.

General Discussion

Previous studies had demonstrated that infants can perceive and respond to objects' physical sizes across changes in distance and retinal image size (Day & McKenzie, 1981; McKenzie et al., 1980; Slater et al., 1990). However, these studies did not determine whether infants' perceptions correspond primarily to objects' constant physical sizes or to the changing sizes of retinal images. Experiment 2 was designed to make a direct comparison of 4-month-old infants' responses to physical and retinal image size. Following habituation, two test objects were presented. One had a novel physical size but a familiar retinal image size; the other had a familiar physical size but a novel retinal image size. The infants showed a significant looking preference for the object that had a novel physical size. In light of the novelty preference found in

Experiment 1, this result indicated that 4-month-old infants perceive an object that has a novel physical size as more novel than an object that has a novel retinal image size, suggesting that infants at this age attend and respond primarily to physical size, not to retinal image size.

How did the infants perceive physical size in this study? The existing evidence suggests that the adult visual system uses two main sources of information to achieve size constancy. Object size can be perceived on the basis of size relationships in the retinal image, such as the relationship between an object's image size and the image sizes of texture elements on the object's supporting surface (Gibson, 1950; Rock & Ebenholtz, 1959). Size can also be computed, via an inference-like process, on the basis of retinal image size and information for object distance (e.g., Rock, 1983). It is unlikely that the infants in this study perceived size on the basis of retinal image size relationships. The objects were suspended in front of a vertical background. Consequently, the ratio between an object's retinal image size and the image size of the background stayed constant between the habituation and test trials for objects that had the same retinal image size but changed when the objects had the same physical size. Image–size relationships, therefore, provided no information for physical size in Experiment 2, and the infants' behavior in this experiment cannot be explained as a response to this information. It therefore seems likely that physical size was perceived on the basis of perceived distance.

No direct test of distance perception was made in Experiment 2. In fact, distance was considered an extraneous variable that had to be controlled. The two test objects were presented at the same distance and at a different distance than that seen during habituation. As a result, distance was controlled in the experiment; discrimination of the test objects had to be based on size and not on distance. Although the study provided no direct evidence that the infants perceived the stimulus objects' distances or retinal image sizes, distance perception and detection of retinal image size can be inferred from the finding that the infants responded to the objects' physical sizes. At some level, the 4-month-old's visual system can apparently compute physical size on the basis of retinal image size and distance. The depth cues used to perceive distance were not identified in this study, but it seems likely that distance perception was based on convergence and binocular disparity, depth cues that 4-month-old infants can apparently use to perceive distance (e.g., see Kellman & Arterberry, 1998).

Although this study provided an answer to one question regarding size perception in infancy, many questions remain unanswered. We do not know, for example, which is more salient to infants younger than 4 months of age: physical or retinal image size. The first experiment of the Slater et al. (1990) study suggested that retinal image size is highly salient to newborn infants. When newborns viewed pairs of objects with varying physical and retinal image sizes, their looking preferences were based on retinal image size, not physical size. This finding suggests that newborn infants may attend and respond to retinal image size over physical size. How newborn infants would respond if tested with the present study's method and whether developmental changes occur in size perception between birth and 4 months of age are interesting questions for future research.

The accuracy of size perception in infants also remains unknown. In the literature on size perception in adults and children, the term *size constancy* is used to refer to accurate perception of physical size across changes in distance and retinal image size; the term *underconstancy* refers to underestimations of size. In the literature on infant perception, the term *size constancy* has been used to describe any response that infants make to physical size that cannot be explained as a response to retinal image size. It is unknown, however, whether infants are capable of actual size constancy. The results of the present study suggest that, on a continuum ranging from a response to retinal image size to perfect size constancy, 4-month-olds' perceptions correspond more closely to size constancy than to retinal image size. But their perceptions may fall within the range of underconstancy, and they could be far from accurate. Day (1987) noted that "while it is now possible confidently to conclude that visual size constancy is operative in infancy, it is not yet possible to state how complete it is" (pp. 85–86). This statement remains true today.

The effects of distance on infant size perception also remain unknown. The accuracy of size perception in infancy most likely depends on viewing distance, as it does in early childhood. Children 4–5 years old can achieve near-accurate size constancy for nearby objects (Tronick & Hershenson, 1979), but they exhibit considerable underconstancy when viewing distances exceed about 3 m (e.g., see Granrud, 2004). It is likely that infants would exhibit underconstancy for distant objects, and the effects of distance on size perception could be even greater for infants than for children. To date, however, infant studies have used only very short viewing distances, and distances beyond 1–3 m remain terra incognita with respect to size perception in infancy.

References

Bower, T. G. R. (1965, July 2). Stimulus variables determining space perception in infants. *Science, 149,* 88–89.

Day, R. H. (1987). Visual size constancy in infancy. In B. E. McKenzie & R.H. Day (Eds.), *Perceptual development in early infancy: Problems and issues* (pp. 67–91). Hillsdale, NJ: Erlbaum.

Day, R. H., & McKenzie, B. E. (1981). Infant perception of the invariant size of approaching and receding objects. *Developmental Psychology, 17,* 670–677.

Fantz, R. L. (1961). The origin of form perception. *Scientific American, 204,* 66–72.

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

Granrud, C. E. (2004). Visual metacognition and the development of size constancy. In D. Levin (Ed.), *Thinking and seeing: Visual metacognition in children and adults* (pp. 75–95). Cambridge, MA: MIT Press.

Kellman, P. J., & Arterberry, M. E. (1998). *The cradle of knowledge: Development of perception in infancy.* Cambridge, MA: MIT Press.

McKenzie, B. E., Tootell, H. E., & Day, R. H. (1980). Development of visual size constancy during the 1st year of human infancy. *Developmental Psychology, 16,* 163–174.

Rock, I. (1983). *The logic of perception.* Cambridge, MA: MIT Press.

Rock, I., & Ebenholtz, S. (1959). The relational determination of perceived size. *Psychological Review, 66,* 387–401.

Slater, A., Mattock, A., & Brown, E. (1990). Size constancy at birth: Newborn infants' responses to retinal and real size. *Journal of Experimental Child Psychology, 49,* 314–322.

Tronick, E., & Hershenson, M. (1979). Size-distance perception in preschool children. *Journal of Experimental Child Psychology, 27,* 166–184.

Received September 8, 2004
Revision received February 13, 2006
Accepted February 17, 2006 ■