INFANCY, *8*(1), 81–90

BRIEF REPORTS

How Infants Encode Spatial Extent

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This study explores how infants encode an object's spatial extent. We habituated 6.5-month-old infants to a dowel inside a container and then tested whether they dishabituate to a change in absolute size when the relation between dowel and container is held constant (by altering the size of both container and dowel) and when the relation changes (by altering only the size of the container but not the dowel). Infants only dishabituated when the relation changed, suggesting that they do not encode the absolute size of either object but only the relation between them.

Developmental psychologists have long been interested in the origin of quantitative and spatial reasoning in infancy. A central question concerns how young children encode continuous quantities, such as the size of an object or the distance between two objects. Piaget and his colleagues claimed that infants and young children have a limited capacity to encode quantitative information about continuous extent until the emergence of measurement skills during the school-age years (Piaget, Inhelder, & Szeminska, 1960). However, recent studies provide evidence that even infants can encode object extent and distance (Baillargeon, Kotovsky, & Needham, 1995; Feigenson, Carey, & Spelke, 2002; Huttenlocher, Duffy, & Levine, 2002). Although these studies show that infants can encode extent, at present

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it is unclear how they do so without measurement skills. This study attempts to address this question by examining whether infants encode the spatial extent of one object as a relation to another object.

INFANT REASONING ABOUT SPATIAL EXTENT

Prior research on infant sensitivity to continuous quantities has focused on both qualitative and quantitative representations of extent (Baillargeon et al., 1995). Whereas qualitative representations involve encoding one object as a general relation to another object (e.g., this rabbit is shorter than the screen), quantitative representations consist of a specific metric relation (e.g., this rabbit is half the size of the screen). In a series of studies, Baillargeon and her colleagues demonstrated that infants exhibit a variety of qualitative representations of size, such as object height in occlusion and containment events (Baillargeon & Graber, 1987; Hespos & Baillargeon, 2001; Hespos & Spelke, 2004), width and distance in collision events (Kotovsky & Baillargeon, 1998), and proportional information about objects in support events (Baillargeon, Needham, & DeVos, 1992).

A number of more recent studies suggest that infants can also encode quantitative information about spatial extent, such as the absolute size of objects, distances, or amounts. This ability is essential for comparing the extents of objects that may be temporally or spatially displaced (Nunes & Bryant, 1996). Gao, Levine, and Huttenlocher (2000) demonstrated that infants are sensitive to changes in a continuous amount of liquid in an experiment in which 6-month-old infants were habituated to a glass cylinder containing a certain amount of red liquid. After habituation, infants were alternately shown a cylinder containing the same amount of liquid as the habituated quantity, and a cylinder containing a novel amount. Infants dishabituated to the container with the novel amount of liquid. There is also evidence that infants can encode information about distance in a continuous space. Newcombe, Huttenlocher, and Learmonth (2000) familiarized 6-month-old infants to an object being hidden at a location within a sandbox 24 in. (60.96 cm) long. Once the infants were familiarized, the experimenter hid the object and subsequently retrieved it from the same location or from a location 6 in. (15.24 cm) away from the hiding location. Infants looked longer at trials in which the object was retrieved from a novel location than at the trials in which the object was retrieved from the hiding location, suggesting that infants encoded the initial hiding location in the sandbox. Finally, Feigenson et al. (2002) demonstrated that 6-month-old infants habituated to a three-dimensional robot-like object dishabituated to a similar object that differed only in size.

Although the studies just cited demonstrate that infants can encode quantitative information about spatial extent, the experiments did not directly address the perceptual basis of these quantitative representations. Piaget's finding that measurement skills emerge in later childhood suggests that it is unlikely that infants impose an external measure on an object (Piaget et al., 1960). However, it is possible that in conditions in which a second object is aligned with the first object, infants may automatically encode extent as the relation or proportion between the two. One common feature of each study previously cited is that the object, distance, or amount was aligned with another object in the stimulus display that may have provided such relative information. For instance, in the Gao et al. (2000) study, the liquid was presented inside a container; in the Newcombe et al. (2000) study, the object was presented inside a red sandbox; and in the Feigenson et al. (2002) experiment, the robots were presented on a small stage. It is possible that in the absence of such background objects infants may not demonstrate sensitivity to extent.

To address this possibility, Huttenlocher et al. (2002) tested whether 6-month-old infants were sensitive to changes in an object's extent in the presence or absence of a second aligned object. Infants were habituated to a dowel either in isolation, inside a clear glass container so that the dowel was visible, or beside a wooden stick. After habituation, infants were alternately shown the habituated dowel and a novel dowel. Whereas infants dishabituated to the novel dowel when it was presented inside the container or beside the wooden stick, they did not look longer at the novel dowel when it was presented in isolation. This finding suggests that infants used the secondary object in encoding the extent of the dowel. However, the Huttenlocher et al. study did not specifically test whether infants encode the relation between the dowel and the aligned object, only that infants encode extent in the presence of an aligned object but do not encode extent in its absence. For example, it is possible that the container merely highlighted the extent of the dowel, or provided a contextual cue for remembering the extent of the dowel (e.g., see Rovee-Collier & Gulya, 2000, for a discussion of such effects in infant memory).

This study directly tests the hypothesis that infants encode the relation between two objects by introducing two between-participants conditions. In both conditions, infants are habituated to a dowel inside a container, and after habituation they are shown the familiar and a novel display in alternation. In the same-ratio condition, the novel display is a dowel and container, both of which differ in height from the familiar stimuli but maintain the same relation as the dowel and container in the habituation trials. In the same-extent condition, the novel presentation is the familiar dowel in a container that differs in height from the habituated container so that the relation between dowel and container changes across familiar and novel presentations. Figure 1 presents a schematic view of these conditions. If infants are sensitive to changes in absolute extent, or if the container merely provides a contextual cue for encoding extent, infants should dishabituate in the same-ratio and same-extent conditions because the absolute extent of both dowel and container change. Alternatively, if infants are sensitive only to the change in proportion be-

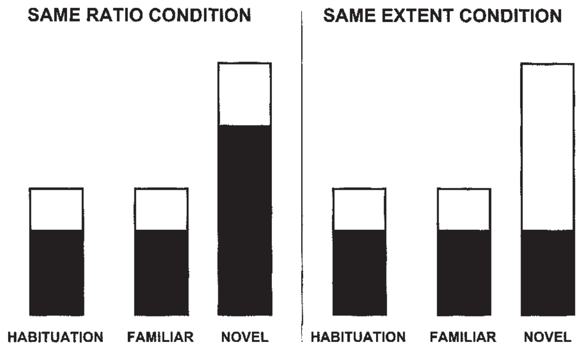

FIGURE 1 Examples of the two experimental conditions used in this study. The white space at the top of each bar represents the clear portion of the glass containers.

tween the dowel and container, they should dishabituate to the novel stimuli only in the same-extent condition, even though the absolute size of the dowel remains constant across familiar and novel trials.

METHOD

Participants

Thirty-two infants (16 boys and 16 girls) participated in the experiment. The mean age of the children was 6.5 months (range = 5 months 23 days–7 months 13 days). An additional 7 infants were excluded from the study for failing to complete all trials due to fussiness or crying (n = 6) or experimenter error (n = 1).

Materials and Apparatus

The experiment utilized two glass containers of differing heights. The height of the small container was 9 cm, and the height of the taller container was 18 cm; both had diameters of 3.5 cm. Two pink wooden dowels, 6 cm and 12 cm in height and 3.3 cm in diameter, served as object stimuli. Note that the dowels used in this experiment are identical to the dowels used in the Huttenlocher et al. (2002) experiment. The stimuli were presented on an enclosed stage that was 120 cm wide, 60 cm deep, and 70 cm high. The infants sat on a parent's lap in a booth that faced the stage. A large screen at the front of the stage could be raised or lowered to occlude the infant's view of the display. The stage was lined with black felt that was draped at the sides to make the edges less salient. Behind the stage, a mounted video camera recorded the infant's eyes through a small hole in the felt. Two 40-watt tungsten lamps illuminated the stage and two 100-watt lamps illuminated the participants through a diffusion screen attached to the ceiling of the booth.

Design

Infants were randomly assigned to the same-ratio and same-extent conditions with the constraint that each condition had an equal cell size. Within each condition, infants were assigned to one of two counterbalanced stimulus size conditions. In the same-extent condition, half the infants were habituated to a 6-cm dowel in a 9-cm container with the novel stimulus being a 6-cm dowel in an 18-cm container. The other half were habituated to a 6-cm dowel in an 18-cm container with a 6-cm dowel in a 9-cm container serving as the novel stimulus. Likewise, in the same-ratio condition, infants were either habituated to a 6-cm dowel in a 9-cm container and tested with a 12-cm dowel in an 18-cm container as the novel stimulus, or a 12-cm dowel in an 18-cm container as the habituation stimulus and the 6-cm dowel in a 9-cm container as the novel stimulus.

Procedure

Infants were tested in a single session lasting approximately 10 min. A parent sat in the booth, holding the infant in his or her lap, 70 cm from the front of the stage. During the procedure, the parent wore a blindfold and was asked to avoid interacting with the infant. There were two experimenters, one who coded the infant's looking time on a computer behind the stage using a monitor connected to the video recorder and one who manipulated the occluding screen and placed the stimuli on the stage. The coder was blind to the infant's experimental condition and could not see the stimuli at any point during the experimental procedure. Participants were tested in three phases.

Familiarization. Infants saw three familiarization trials with no stimulus present on the stage. These trials served to accustom the infant to the screen movement. The experimenter raised the occluding screen for 7 sec, then lowered it, at which point a bell rang to direct infants' attention toward the stage. Each familiarization trial lasted until the infant looked away from the stage for 2 consecutive seconds, at which point the experimenter raised the screen and repeated the trial. The time was recorded by a computer that measured the length of time the coder pressed the spacebar and indicated the end of the trial by emitting a beep to the experimenter controlling the screen.

Habituation. Each habituation trial began with the screen occluding the stage. The habituation stimulus was placed at the center of the stage approximately 80 cm from the infant. The experimenter released a screen and rang the bell. The observer then recorded the infant's looking on a computer. Each trial lasted until the infant looked away from the stimuli for 2 consecutive seconds, at which point the computer signaled that the trial was complete. At the end of the trial, the experimenter again occluded the stage for approximately 7 sec, during which time the experimenter removed and replaced the habituation stimulus so that any sound produced by manipulating the stimulus remained constant across all habituation and test trials. The experimenter repeated the habituation trials until the infant's mean looking time on three consecutive trials was less than half the mean looking time on the first three habituation trials.

Test trials. Four test trials were presented, alternating between the familiar and novel displays. Except for the stimuli, the procedure was identical to the habituation portion of the experiment. During the test phase, the order of presentation (novel or familiar display presented first in the test trials) was counterbalanced. Postsession interrater correlations of infants' looking time were assessed on 25% of the sessions and ranged from .90 to .96, with an average of .92.

RESULTS

We performed a split-plot analysis of variance (ANOVA) with 1 within- and 3 between-participant factors: condition (same-ratio or same-extent), test trial presentation order (familiar or novel stimulus shown first in the test trials), size of habituated container (small or large), and gender on mean looking times on the two novel and two familiar test trials for each infant. This analysis yielded a main effect for test condition and a significant interaction between test condition (same-ratio and same-extent) and test trial (novel and familiar display), $F(1, 17) = 8.891$, $p < .01$, effect size = .30. This effect emerged due to the increased looking time at the novel stimulus for infants in the same-extent condition, but not in the same-ratio condition. In the same-extent condition, mean looking time at the familiar display was 3.61 sec ($SD = 2.28$) and at the novel display was 5.87 sec ($SD = 3.71$), whereas in the same-ratio condition, mean looking time to the familiar display was 3.80 sec ($SD = 2.54$) and to the novel display was 3.63 sec ($SD = 2.27$). Figure 2 presents these data. To confirm the results of the ANOVA, we performed paired t tests on the looking times to the novel and familiar displays within each condition. This analysis yielded a significant effect for difference in mean looking time in the same-extent condition, $t(15) = 3.28$, $p < .01$, but no significant difference in the same-ratio condition, $t(15) = 0.68$, $p = .5$. In addition, the results did not arise due to the performance of a minority of infants. In the same-ratio condition, 8 of the 16 infants exhibited increased looking time to the novel stimulus ($p < .5$, binomial test), whereas in the same-extent condition, 13 of the 16 infants exhibited increased looking times ($p < .05$, binomial test).

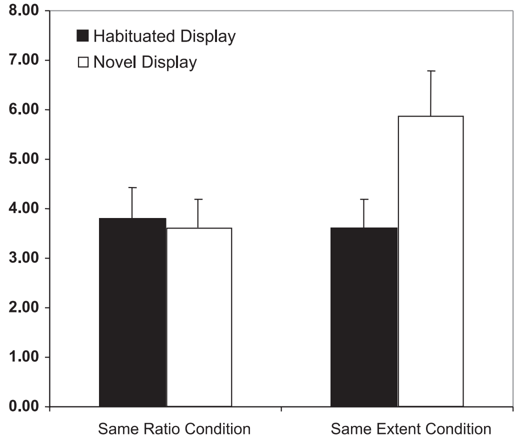

FIGURE 2 Looking time (in seconds) at the familiar and novel displays by condition. Bars indicate 1 standard error of measurement.

The results of the experiment suggest that infants encoded the relation between the dowel and the container. They do not appear to perceive the change in absolute size of either the habituated dowel or the container when the relation between the two is held constant. Infants in the same-ratio condition presented with a novel-size dowel in a novel-size container that had the same relation as the dowel and container in the habituation display did not look longer at the novel display. In contrast, infants in the same-extent condition dishabituated to a novel display consisting of the familiar-size dowel in a novel-size container, in which the relation between dowel and container changed. This indicates that infants noticed the change in the relation between the dowel and the container even though the extent of the dowel remained the same. If infants encoded absolute extent without relying on the relation between the dowel and container, they would have dishabituated in the same-ratio condition in which the extent of the dowel and container changed between novel and familiar trials. These results support the hypothesis that infants encoded the relation between the two objects but are not sensitive to changes in their absolute extents. However, one additional interpretation is that infants in the same-extent condition noticed the change of the empty portion of the container, which was larger in the same-extent than the same-ratio condition. Yet this possibility is unlikely, given the fact that the change in the empty portion of the container (3 cm to 6 cm and vice versa) is smaller in absolute terms than the change in the absolute size of the pink dowel in the same-ratio condition (6 cm to 12 cm and vice versa).

GENERAL DISCUSSION

A variety of recent studies have demonstrated that infants can encode information about an object's extent, yet few studies have addressed what perceptual information forms the basis for such quantitative representations. The findings reported here indicate that infants do not attend to information about an object's absolute extent but rather encode the relation between the extents of two aligned objects (in our case, a container and a wooden dowel).

Many prior studies demonstrating infant discrimination of both discrete and continuous quantities failed to consider the role of relative information in infants' ability to discriminate between quantities that vary in amount (Mix, Huttenlocher, & Levine, 2002). We have found that once relative information is either controlled for or unavailable, infants do not attend to a 50% change in the size of the two objects. Although it may be possible that under certain conditions infants may demonstrate sensitivity to a change in the absolute extent of an object in which the difference in size is drastic (e.g., from 1 in. [2.54 cm] in height to 10 ft [3.05 m] in height) or when the change in size is not spatially or temporally displaced, the purpose of this study was to provide insight into how infants might encode spatial extent without having measurement skills.

The capacity to encode the relative size of two objects resembles the adult strategy of measuring the extent of an object in relation to a standard object such as a ruler. However, an important difference is that older children and adults impose measures on objects. Such measures may be a conventional measuring device, an idiosyncratic unit such as a hand span, or a remembered extent such as a memory for the average length of a car. To determine the equivalence of different quantities, adults use the same measure across object comparisons. In contrast, infants and young children do not demonstrate a capacity to impose standards when one is not present in the immediate perceptual environment (Huttenlocher et al., 2002; Piaget et al., 1960). When a measure is available in the form of an aligned secondary object, spatial extent is encoded only as the relation between the sizes of the two objects. This strategy is effective under conditions in which the aligned object is the same across comparisons or maintains a constant extent. However, when a different aligned object is used, or if the object changes size between object comparisons, this strategy fails because the relation no longer provides useful information for comparing extent.

Although adults typically impose a constant measure on objects they measure, they may sometimes use the strategy of encoding extent relative to objects in the immediate surrounding context under certain perceptually impoverished conditions (Rock & Ebenholtz, 1959). When a constant measure is unavailable or not used, adults often misperceive the absolute size of objects. For example, the moon illusion is caused by the use of relative information provided by visual cues on the horizon that result in the moon appearing larger near the horizon than at the zenith (Baird, Wagner, & Fuld, 1990). Anecdotally, many people have experienced the frustration of buying a piece of furniture that looked small in the large warehouse but, after delivery, looks huge in the small living room. The phenomenon we have observed in infants may be related to a more general perceptual bias for encoding stimulus relations, available from an early point in development (see Reese, 1968, for a review of earlier work on this topic).

Although these data are suggestive, several issues have yet to be resolved. First, given the dissociation between neural pathways for perception and action, it is unclear whether our finding is restricted only to the visual perception of extent. Because sensitivity to size is crucial for action, it is possible that action-based representations encode information about absolute extent at earlier ages than perceptual representations (see Clifton, Rochat, Litovsky, & Perris, 1991). Second, this study only addresses representations of extent in a static display at a fixed distance. It is possible that in a dynamic display involving occlusion, containment, or collision events, or in cases where the object moves toward or away from the infant, the absolute size of an object may be more readily perceived (e.g., see Aguiar & Baillargeon, 1999; Slater, Mattock, & Brown, 1990; Wilcox & Schweinle, 2003). Third, it is unclear whether infants' failure to dishabituate to the novel stimulus in the same-ratio condition is due to their inability to detect the change in absolute size or because they detected the change but categorized the novel stimulus as a member of the same class of stimuli as the habituation stimulus. A final issue is whether this ability to encode relative extent might be related to the development of other quantitative skills, such as the enumeration of discrete quantities or the later emergence of conventional measurement skills (Clearfield & Mix, 1999). Future research should explore the relation between this early ability to encode relative information and the emergence of quantitative reasoning in both continuous and discrete domains.

ACKNOWLEDGMENTS

This research was supported by National Science Foundation Grant BCS9904315 to Janellen Huttenlocher. We thank the editor and three anonymous reviewers for their comments on earlier drafts of this article.

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