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Amount Versus Number: Infants' Use of Area and Contour Length to Discriminate Small Sets

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Previous research has reported that infants use amount rather than number to discriminate small sets (Clearfield & Mix, 1999). This study sought to replicate and extend this finding. Experiment 1 confirmed that infants respond to changes in contour length but not to changes in number when contour length is controlled. However, contour length and area were confounded in this experiment and the original study. To determine what specific measure of spatial extent infants use to discriminate small sets, Experiment 2 included 2 conditions that varied either area or contour length, but not both. As before, infants responded to the changes in spatial extent—either contour length alone or area alone—but not to the changes in number.

Previous research using habituation has shown that even very young infants react to changes in quantity (Antell & Keating, 1983; Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1990; Strauss & Curtis, 1981). In these studies, infants repeatedly are shown static visual sets containing a certain number of items (e.g., two dots). After looking time decreases to a criterion, infants are shown test displays with either the familiar set size or a novel set size (e.g., two vs. three dots). The consistent finding is that infants look longer at the display with the novel number of items.

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Most investigators have assumed that infants' responses in these studies were based on a discrete number. Some argued that infants use a mechanism that counts individual items by emitting pulses at a constant rate and gating one pulse per item into a container called an accumulator (Gallistel & Gelman, 1992; Wynn, 1995). The resulting fullness of the accumulator represents the total quantity of the set. Other investigators have proposed that infants tag individual items with object tokens. These tokens are thought to be by-products of the way the visual system parses up a scene (Simon, 1997; Trick & Pylyshyn, 1994; Uller, Carey, Huntley-Fenner, & Klatt, 1999). In contrast to the accumulator explanation, it has been argued that the assignment of object tokens is not an operation specifically designed for numerical processing (Simon, 1997). Still, both processes require attention to the number of discrete individuals.

In principle, however, quantification does not require attention to the number of individuals. It is possible instead to use overall amount (i.e., spatial extent). This could be determined by estimating the surface area encompassed by the layout of the items—as if a line were drawn around them—or by mentally combining the areas of the items themselves. Similarly, one could estimate the contour length either for the entire space or accrued over individual items. In a set of three-dimensional objects, quantity estimates could be based on the total volume. In short, there are several continuous variables that could be used to quantify a set.

In fact, there is mounting evidence that infants use these continuous variables, rather than number, to perform quantitative tasks. First, infants' discriminations in the number habituation task may be based on spatial extent. Clearfield and Mix (1999) habituated two groups of infants to sets of two or three squares of the same size. At test, both groups of infants saw two alternating displays—one with the familiar number but a change in spatial extent (based on total contour length) and one with a novel number ($n \pm 1$) but the same overall amount of contour as the habituation trials. It is important that the contour-length change was the same as if there had been the addition or subtraction of a square. The key finding was that infants looked significantly longer at the change in amount but not in number. This suggests that when infants recovered responding in previous studies, their responses were based on spatial extent. Because this finding has significant theoretical implications, it is important to confirm that it is correct. One goal of this study is to provide such a test by attempting to replicate Clearfield and Mix's experiment.

Spatial extent also may underlie infants' responses in calculation tasks (Simon, Hespos, & Rochat, 1995; Wynn, 1992). In these experiments, infants were shown simple addition and subtraction problems using dolls. For example, they watched as one puppet was placed behind a screen and then a second puppet was placed behind the same screen. Next, the screen was lowered to reveal either one or two puppets. Infants looked longer at the incorrect solution, which Wynn interpreted as surprise at the incorrect answer. This led Wynn to conclude that they performed precise calculations over discrete number. However, Feigenson and Spelke (1998) questioned whether infants attended to the change in volume (i.e., amount of doll) rather than the change in number. They used Wynn's procedure but manipulated the size of the puppets to control for volume. For instance, after watching two small puppets being placed behind a screen, infants saw either one large puppet (same volume) or two large puppets (same number). Infants only looked longer toward an unexpected change in volume. Thus, as in Clearfield and Mix's (1999) habituation study, infants appeared to use spatial extent instead of number.

Although the assertion that infants use spatial extent in quantitative tasks is new, the idea that infants are sensitive to amount is not. Several studies have shown that infants' visual preferences are determined by spatial extent rather than several other perceptual features, such as spatial position or figure complexity (Karmel, 1969; McCall & Kagan, 1967; McCall & Melson, 1970; Pipp & Haith, 1984; Salapatek, 1968; Salapatek & Kessen, 1966). For example, 5-month-olds responded to changes in total contour length and surface area but not to changes in spatial arrangement (McCall & Melson, 1970). That is, when the spatial positions of elements in a set were held constant, but the total contour length and surface area of the shapes varied, 5-month-olds showed differences in visual attention. However, when contour length and area were held constant, infants showed no preferences based on spatial position. That infants responded to contour length and area in these studies demonstrates that amount is a salient feature of the environment that captures infants' attention.

In fact, when spatial extent has been pitted directly against number in visual preference studies, it is amount that determines infants' looking patterns (Brennan, Ames, & Moore, 1966; Fantz & Fagan, 1975; Fantz, Fagan, & Miranda, 1975). In these studies, infants were shown pairs of displays with simple shapes, such as black squares on a white background. When both displays had the same size items, infants preferred the display with more items. When the number of items was held constant across displays, infants preferred the display with larger items. Thus, infants preferred to look at displays with a greater overall amount of surface area.

Infants also demonstrate sensitivity to changes in amount of continuous quantities. For example, Gao, Levine, and Huttenlocher (2000) habituated 5-month-olds to containers with a particular amount of red liquid. At test, infants looked significantly longer when a different amount was shown. This is the same pattern as that reported in number habituation experiments.

Taken together, these findings indicate that spatial extent plays an important role in infants' sensitivity to quantity. Moreover, in contrast to accounts that posit an abstract enumeration process, this suggests that infants' quantification is rooted in visual perception. It is well known that infants focus on edges and surface area when they are scanning all kinds of visual images, including faces, abstract patterns, and shapes (e.g., Bronson, 1991; Haaf, Smith, & Smitely, 1983; Sherrod, 1979). Attention to these high contrast features may help infants parse visual scenes (e.g., McCall & Melson, 1970). The same features also can be used to estimate amount. In other words, as infants scan the edges of displays, the information they are processing may be the overall amount.

What remains unclear is which of these features—contour length or area—infants use in habituation to number experiments. In Clearfield and Mix's (1999) study, contour length was varied because it is known that infants are sensitive to it. However, no attempt was made to separate contour-length changes from area changes. Thus, it is unclear whether infants recovered responding to the change in contour length alone, area alone, or both combined. We know from perceptual research that infants are sensitive to both features (Pipp & Haith, 1984). Thus, a second goal of this study is to explore the specific parameters of spatial extent that infants use to discriminate small visual sets. In particular, this may be useful in future attempts to model infant quantification.

We present two experiments here. Experiment 1 is an attempt to replicate Clearfield and Mix's (1999) finding that infants use contour length, and not number, to discriminate small sets during a habituation task. Experiment 2 extends this research by separating area from contour length to determine whether infants could use either feature alone to discriminate quantity.

EXPERIMENT 1

Method

Participants. Twelve 6-month-old infants (6 boys and 6 girls) participated in this study ($M = 6.07$ months; range = 4.7–7.1 months). An additional 12 infants were excluded due to distraction during habituation (4), failure to look at the displays (3), and fussiness (5). Infants were recruited through local published birth announcements, and then their parents were contacted by mail. All infants received a small gift for participating.

Design. The design of this experiment was the same as the design of Clearfield and Mix (1999; see Figure 1). Infants were habituated to either two or three squares of the same size. Then, those infants who were habituated to two squares were shown a total of four test trials, alternating between two test displays: change in contour length (i.e., two larger squares, resulting in more contour length) and change in number (three smaller squares, resulting in the same contour length as the habituation displays). Those infants who were habituated to three squares also were shown a total of four test displays, alternating between two test displays: a change in contour length (i.e., three smaller squares, resulting in a smaller contour length) and a change in number (two larger squares, resulting in the same total contour length as the habituation displays). The order of the test displays was counterbalanced across infants. Thus, each infant participated in one of four conditions (the number of squares in the habituation displays and the order of the test trials) that result when these two variables are crossed.

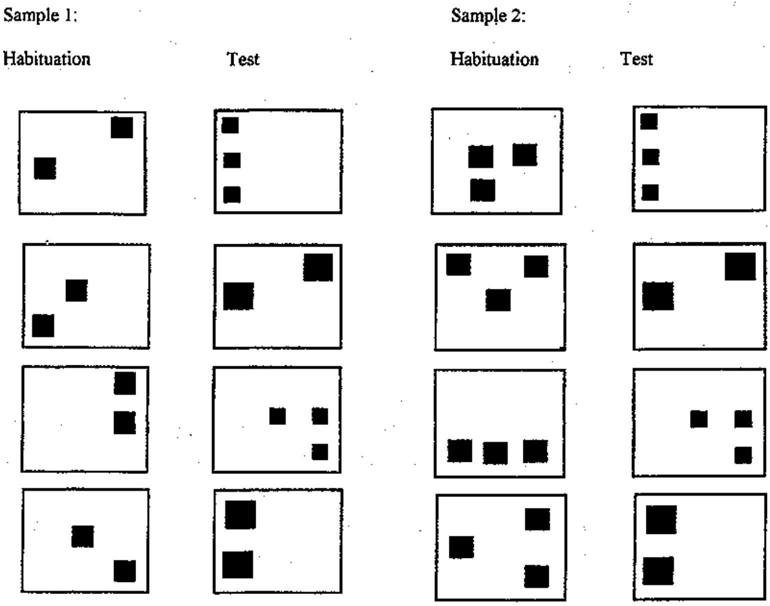

FIGURE 1 Sample habituation and test trial displays for Experiment 1.

Contour length was defined as the total perimeter summed over the individual items. For example, if infants were habituated to two squares with a total contour length of 16 cm (i.e., 8 cm per square), then the test trials would be three squares with a total contour length of 16 cm and two squares with a total contour length of 24 cm. Note that 24 cm is what the contour length of the original test display would have been had we simply added another square of the same size (i.e., three squares at 8 cm each equals 24-cm total contour length). Likewise, infants were habituated to three squares with a total contour length of 24 cm (8 cm each) and tested on displays of three squares with a total contour length of 16 cm or two squares with a total contour length of 24 cm. We chose this particular change because it is equivalent to the contour-length differences in previous studies in which number and contour length were confounded. Thus, if infants in this study responded to such small changes in contour length, it would be reasonable to conclude that infants may have responded to previous studies on the basis of these changes.

Apparatus. Infants sat in an infant seat located 30 cm from the display in a small, quiet room surrounded by black curtains. The stimulus displays were computer-generated drawings of black squares on a 21.5- × 28-cm white background. These were mounted on foam board. Stimulus cards were slid in and out of an opening in the black curtain directly in front of the infant. A rubber stopper was attached to the far end of the opening to ensure that display cards were placed at the same location for every trial. One experimenter presented the stimulus cards while a second experimenter recorded looking time on a computer. The computer program tabulated looking times for the first three trials and then used a moving window to compare each successive set of three trials until looking time decreased by half. The computer then signaled the first experimenter to begin the test trials.[1] The experimenter recording looking time was thus unable to tell what displays were being presented.

Procedure. Infants were secured in the infant seat on a table facing the display. Parents sat directly behind the table and wore dark sunglasses so that they could not see the displays. Infants were presented with a maximum of 16 habituation trials. During these trials, the displays had squares with the same number and contour length but different spatial locations based on the displays used by Starkey et al. (1990). Trials commenced as soon as the infant first fixated on the display and lasted for 10 sec. Infants were shown habituation displays until the average looking time for three consecutive trials was half of the average looking time for the first three habituation trials. The average number of habituation trials needed to reach criterion was 11 sec. Infants then were shown the four alternating test trials.

Results and Discussion

To test the reliability of the online coder, a second coder who was blind to the experimental conditions measured looking time from 20% of the videotaped sessions. Interrater agreement was high (.98); thus, the online recordings were used in all subsequent analyses. A summary of the average looking times is presented in Figure 2. As shown in Figure 2, infants looked longer at the change in contour length than the change in number. To determine whether this difference was significant, a 2 (sex: boy vs. girl) × 4 (condition) analysis of variance (ANOVA) was conducted on infants' average looking time for each type of test trial (number vs. contour length). The four conditions resulted from crossing the number that infants were habituated to (two or three) with the type of test trial seen first (change in contour length or change in number). Indeed, there was a main effect for test trial type, with longer looking times for the change in contour length, $F(1, 3) = 13.44, p < .01$. Be-

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[1] To ensure habituation, all infants were shown at least eight habituation trials. We reasoned that if an infant actually recovered in fewer trials, presenting additional habituation displays would have no effect.

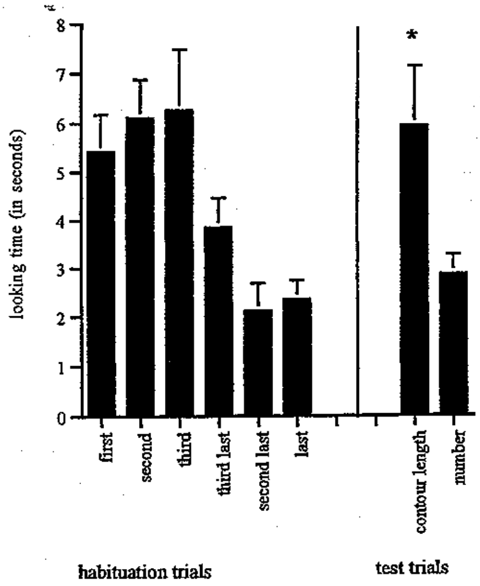

FIGURE 2 Mean looking times at habituation and test trials for Experiment 1, $*p < .01$.

cause there were no other significant main effects or interactions, the data were pooled across sex and condition for all subsequent analyses.

This difference in looking times suggests that infants did not react to the change in number. To test this, we next examined differences in looking times between the habituation and test trials. We used paired *t* tests to compare the average looking time during the last three habituation trials to the average looking time for the two test trials of each type (i.e., contour length and number). There was a significant increase in looking time for contour length, $t(11) = 4.121, p < .001$, but not for number, $t(11) = .174$, *ns*. Thus, infants detected the change in contour length, but there is no evidence that they detected the change in number. These results replicate those reported by Clearfield and Mix (1999).

One could argue that infants only responded to the change in spatial extent when it was pitted directly against number. That is, because the test trials alternated a number change with a contour-length change, infants may have preferred the change in contour, given a choice, but would have recovered looking time to the number change if that had been the only test trial. Of course, there was no reason that infants could not recover in both test conditions. Furthermore, the lack of a significant interaction with order casts doubt on this interpretation. That is, under this interpretation, infants should only look longer at the contour-length change when the change in number was presented second. However, we can be sure that the failure to recover to the change in number was not due to a spatial extent preference by analyzing participants' looking times on the first test trial. On the first test trial, one half of the infants saw the number change, and one half saw the contour-length change. Thus, there was no choice involved on these test trials because, at this point in the experiment, infants had no reason to anticipate a different kind of test display. When these first trial looking times were compared to those on the last habituation trial, we found the same pattern as before. Infants recovered to the change in contour length, $t(5) = 4.04, p < .01$, but not to the change in number, $t(5) = .68$, *ns*.

EXPERIMENT 2

In Experiment 1, contour length was manipulated to control spatial extent because this variable is known to capture infants' attention. We allowed the surface area of the squares to covary with contour length, as it does in natural environments. That is, as the contour length of each square changed, the area did as well. However, to understand how infants use amount to quantify a set, it is important to know which measure of spatial amount—area or contour length—infants use. This could be critical in future modeling of this early quantification process, as well as in understanding its neural components. Experiment 2 separates these factors. We examined whether infants respond to a change in area when contour length is controlled across habituation and test trials, and vice versa.

Method

Participants. Thirty-two 6-month-old infants (19 boys and 13 girls) participated in this study, with 16 in each condition ($M = 6.12$ months; range = 5.1–6.9 months). In the area-change condition, there were 9 boys and 7 girls. In the contour-length change condition, there were 11 boys and 5 girls. An additional 7 infants were excluded from the analyses due to failure to look at the displays (4) and fussiness (3). Infants were recruited through local birth announcements, and their parents were contacted by mail. All infants received a small gift for participating.

Design. The design was similar to Experiment 1. Infants were randomly assigned to either the area change or the contour-length change condition. In the area-change condition, infants were shown test trials that alternated between changes in area and changes in number, whereas contour length remained constant across habituation and test trials. The area varied between habituation and test trials in the same manner as in Experiment 1. For example, in one variation, infants were habituated to two abstract shapes of 16-cm^2 total area (i.e., 8 cm^2 per shape). The test tri-

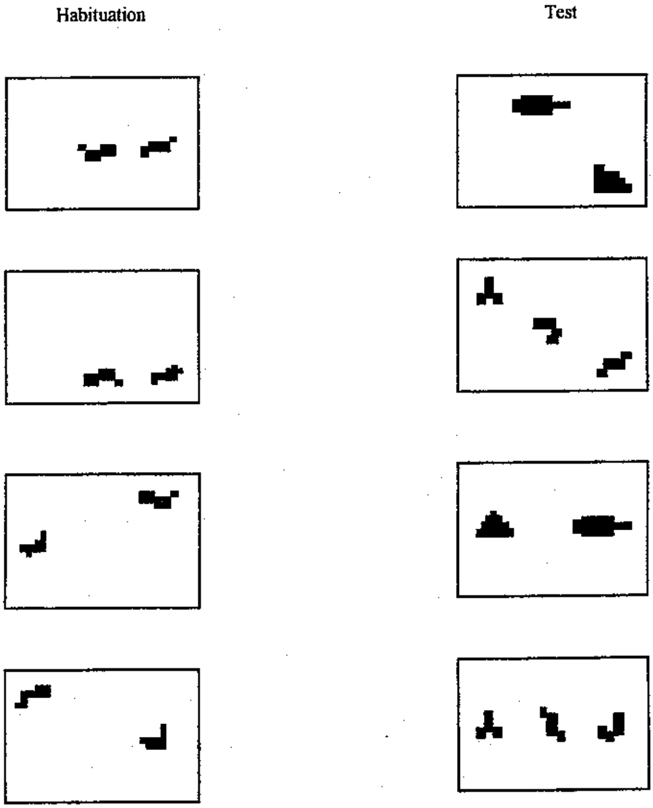

FIGURE 3 Sample habituation and test trials displays for Experiment 2 when contour length was held constant across habituation and test displays.

als were three shapes with a total area of 16 cm^2 and two shapes with a total area of 24 cm^2. Note that 24 cm^2 is what the area of the original test display would have been had we simply added another shape of the same area (i.e., three shapes at 8 cm^2 each equals 24 cm^2 total area). To keep contour length the same throughout habituation and test trials while varying area, the resulting stimuli were abstract shapes (see Figure 3).

In the contour-length variation, infants were shown test trials that alternated between changes in contour length and changes in number, whereas area remained constant across habituation and test trials. The contour length varied between habituation and test trials in exactly the same manner as before, except that area was kept constant. Again, to do this, the resulting stimuli were abstract shapes (see Figure 4).

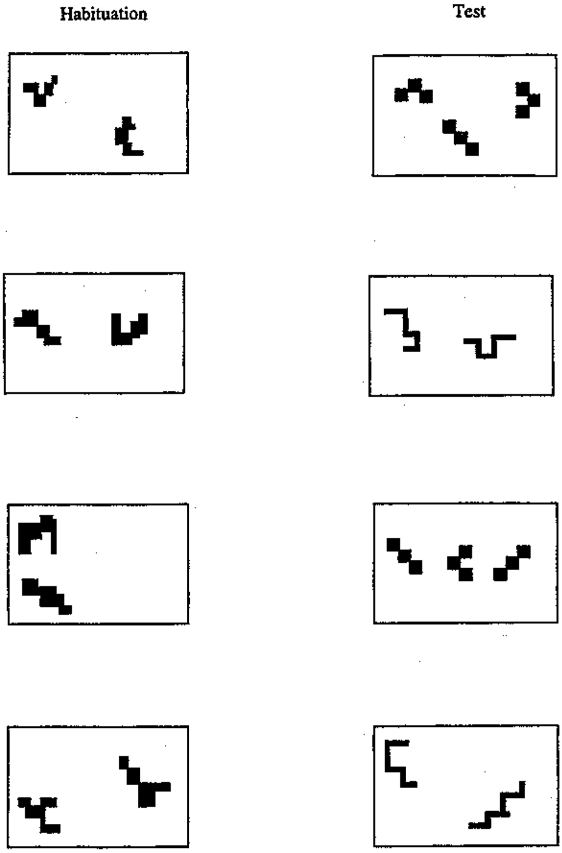

FIGURE 4 Sample habituation and test trials displays for Experiment 2 when area was held constant across habituation and test displays.

Apparatus and procedure. The apparatus and procedure were the same as Experiment 1.

Results and Discussion

A coder who was blind to infants' assigned conditions coded 20% of the videotaped sessions. Interrater reliability was high (.91); thus, the online observations were used in the following analyses. Figures 5 and 6 depict infants' looking times on the critical trials for area-change condition and contour-length change condition, respectively. An inspection of these data reveals that infants looked longer at the change in either measure of spatial extent than the change in number. To test whether these differences were significant, a 2 (sex) × 4 (condition) ANOVA was conducted on infants' average looking time for each type of test trial (change in number vs. change in amount). Again, the four conditions resulted from crossing the number infants were habituated to (two or three) and the type of test trial seen first (change in amount or change in number). This analysis confirmed that infants looked longer at the change in spatial extent than the change in number, $F(1, 3) = 13.614$, $p = .001$. There were no main effects for sex or condition; thus, the data were pooled across these variables for all subsequent analysis.

Next, we examined infants' looking-time patterns across the habituation and test trials. Because we were interested in whether infants react to changes in area alone or contour length alone, we divided the data into two conditions and analyzed them separately. Paired *t* tests were used to compare the average looking time across the last three habituation trials to the average looking times across both test trials of each type. These tests showed that infants looked significantly longer both when area changed, $t(13) = 3.0$, $p < .01$, and when contour length changed, $t(13) = 4.16$, $p < .01$. Thus, it appears that infants can use either measure of amount to discriminate. In contrast, infants did not recover attention to the number change in either condition: area, $t(13) = .54$, *ns*, and contour length, $t(13) = .45$, *ns*. This is consistent with the results of Experiment 1 and previous studies that indicated infants do not use number in these discriminations.

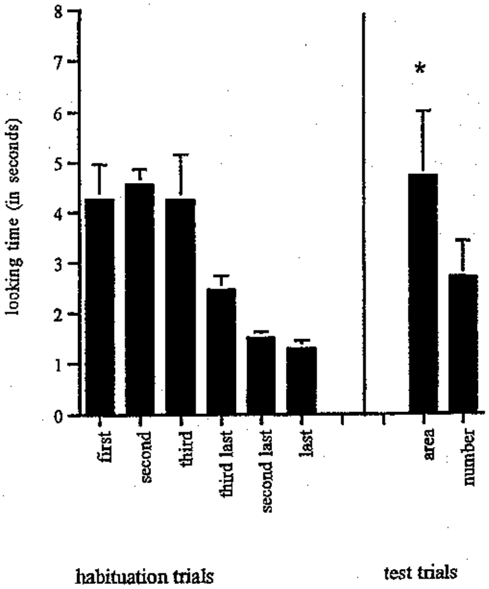

FIGURE 5 Mean looking times at habituation and test trials when contour length was held constant and area and number were manipulated, $*p < .01$.

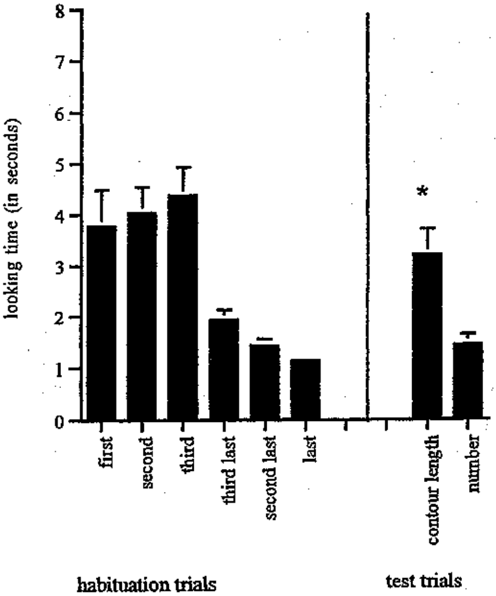

FIGURE 6 Mean looking times at habituation and test trials when area was held constant and contour length and number were manipulated, $*p < .01$.

We next analyzed the data from the first test trial separately for those infants who saw the change in amount first and those who saw the change in number first. Again, we analyzed the data from the change in area condition separately from the change in contour-length condition. This allowed us to determine whether infants' failure to recover to the number change was due to a preference for amount when it was pitted against number. We obtained the same pattern as when the data were pooled across test trials. Infants recovered to the change in area, $t(7) = 2.96, p < .05$, and to the change in contour length, $t(7) = 3.22, p < .05$, but they did not recover to the changes in number in either condition: area, $t(7) = .93$, *ns,* or contour length, $t(7) = .77$, *ns*. Although infants who saw the change in number first had no reason to anticipate a change in amount, they still failed to recover on the first test trial. This indicates that infants do not simply prefer changes in amount. Instead, changes in amount may be all that they perceive.

The aim of Experiment 2 was to determine which aspects of spatial extent infants use in the quantity-habituation task. We found that infants detected changes in area when contour length remained constant, and they detected changes in contour length when area remained constant. In no case did infants detect changes in number when both contour length and area remained constant. Thus, it appears that infants detect changes in quantity based on either area or contour length. However, there is one drawback to this experiment that mitigates this conclusion: To create stimuli that varied in contour length but not area, noticeable changes in shape were necessary. Longer contour lengths required long, thin, snake-like objects, whereas shorter contour lengths with the same area required more block-shaped objects. Thus, infants' discriminations when area was held constant may have been based on changes in shape rather than contour length. The close relations among shape, area, and contour length may make it impossible to test contour-length changes in isolation.

GENERAL DISCUSSION

This study investigated the claim that infants respond to amount rather than number in habituation to quantity experiments (Clearfield & Mix, 1999). First, we found that infants recover looking to changes in contour length when number is held constant but do not recover looking to changes in number when contour length is held constant. This replicates Clearfield and Mix's results, adding support to the claim that infants attend to amount rather than number in these tasks. We further demonstrated that this pattern of responding was not simply based on a preference for amount when it is pitted against number. When the first test trial responses were analyzed between participants, there was no evidence that infants responded to number even before they knew that an amount change would occur. However, infants did respond to changes in amount before the number change was presented.

Previous research did not specify whether infants use contour length, area, or the two combined to estimate amount. Our results indicate that infants can use area alone or in combination with contour length. We also obtained evidence that infants respond to a change in contour length when area is held constant. However, because the stimuli in this condition also changed in shape, it is unclear whether infants actually used contour length in isolation. Still, by establishing that infants can estimate quantity based on area, it may be possible to develop models that can explain precisely what aspects of the visual system are involved in processing quantitative information.

These results add to a growing literature that calls for a change in the conceptualization of early quantitative development (Clearfield & Mix, 1999; Feigenson & Spelke, 1998; Gao et al., 2000). Habituation and calculation studies have amply demonstrated that infants are sensitive to quantity (Antell & Keating, 1983; Simon et al., 1995; Starkey & Cooper, 1980; Starkey et al., 1990; Strauss & Curtis, 1981; Wynn, 1992). For many years, investigators assumed that this sensitivity is based on discrete number. In fact, some have claimed that infants are endowed with a number-specific counting mechanism (Gallistel & Gelman, 1992; Gelman, 1991; Starkey, 1992; Wynn, 1995, 1997). Other proposed mechanisms that are not number specific, such as the object file hypothesis (Simon, 1997; Uller et al., 1999), nonetheless hold that infants represent quantity in terms of individual items.

However, these findings suggest an alternative starting point—one that is based on a general sense of amount rather than discrete number. This is not to say that infants are unaware of distinct individuals. Indeed, it is well known that infants can use spatiotemporal information to individuate objects from an early age (e.g., Kellman & Spelke, 1983; Xu & Carey, 1996). Still, it is possible to have an awareness of individuation without applying this information in quantitative situations. In fact, our results suggest that infants generate estimates of overall amount despite the presence of individuals.

This account has important developmental implications. Because number and amount tend to covary in the environment, an undifferentiated sense of quantity would be sufficient to discriminate between amounts in most situations well into early childhood (Mix, Huttenlocher, & Levine, in press). For example, an infant could notice that one pile has more toys than another without knowing the number of toys in the two piles. Similarly, a child who sees that the quantity of raisins on his plate changes as he eats would not need to count to learn about decrementation.

At some point, children must discover that continuous and discrete quantities are distinct. However, when and how this is accomplished remains unknown. Indeed, much of the research on early childhood number concepts actually may have tapped a general sense of amount because the stimuli involved were not controlled for size. For example, Mix (1999) reported that preschool children can match identical sets of objects (e.g., two dots equals two dots) earlier than they can match dissimilar sets (e.g., two dolls equals two dots). One reason might be that the items in the identical sets matched in amount in a way that the dissimilar sets did not.

Although the claim that infants represent quantities as overall amounts seems well supported, this interpretation raises new questions. First, it is unclear whether the underlying mechanism is specific to quantity. The issue of domain specificity has been central in discussions of quantitative development (Gelman, 1991; Simon, 1997; Wynn, 1997). However, both sides in this debate have accepted the premise that infants process discrete number. In light of these results, we believe that a domain-specific mechanism for number (or amount) would be superfluous, given the nonspecific neural mechanisms that are available to infants and that could enable amount estimation. In fact, it already is well known from studies of perceptual development that infants focus on edges and surface area when they are scanning all kinds of visual images, including faces, abstract patterns, and shapes (e.g., Bronson, 1991; Haaf et al., 1983; Sherrod, 1979). It is thought that attention to these high contrast features helps infants parse visual scenes (e.g., McCall & Melson, 1970). Because attention to these features is already a part of infants' natural visual preferences, a separate mechanism responsible for attention to number or amount would be redundant.

Comparative research reports similar findings in rats, chicks, and cats, suggesting that responses to amount are a primitive feature of perception—one that transcends species (Hubel & Wiesel, 1962; Karmel, 1969). This research has identified cells in the visual system that respond exclusively to contour information (Hubel & Wiesel, 1962). There are significant increases and decreases in the activity of these cells in response to sharp changes in light gradient (i.e., contour). This spiking activity is tied closely to the stimulus characteristics, such that the activity of these cells increases as amount of contour increases.[2] Thus, it is unnecessary to invoke a domain-specific mechanism to explain infants' responses to quantity. These responses could result instead from basic visual processes used to parse a scene.

A second question is how to integrate these results with performance on quantitative tasks that do not involve visual sets of objects. Although habituation and calculation studies provide the majority of evidence that infants are sensitive to quantity, two other experimental paradigms that do not require comparisons between static object sets also have been used. One of these tested whether infants can detect equivalence in an intermodal task (Starkey et al., 1990). Seven-month-olds were shown pairs of visual displays that included one display of two objects and one display of three objects. While the displays were still visible, either two or three drumbeats were played. Infants responded by looking longer toward the display that matched the number of sounds. This has been interpreted as evidence that infants can perceive the number of distinct entities both in a sequence of sounds and a static visual display, and can relate these sets to one another in terms of numerical equivalence—an accomplishment that would be difficult using a representation of amount.

However, subsequent research has questioned whether infants actually can detect these intermodal correspondences. Two attempts to replicate Starkey et al.'s (1990) finding have obtained the opposite pattern of response: Infants looked longer at the display that was not equivalent (Mix, Levine, & Huttenlocher, 1997; Moore, Benenson, Reznick, Peterson, & Kagan, 1987). Because the effects in all three studies were small and in opposite directions, it is possible that the reported effects actually are due to random variation. However, even if there is a real preference in these studies, it may not be based on discrete number. Mix et al. found that infants do not show a significant looking preference when the rate and duration of the drumbeat sequences is varied randomly. Thus, infants in the previous experiments may have been matching on the basis of overall amount (i.e., amount of time to amount of area).

Other quantitative studies with infants have used events instead of objects (Canfield & Smith, 1996; Wynn, 1996). For example, Wynn habituated infants to

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[2] At some point, cell activity peaks and then decreases as increasing amounts of contour are presented.

sequences that contained the same number of puppet jumps (either two or three). The rate and duration of sequences were varied so that infants could not use these cues to discriminate between sets. At test, infants saw an alternating series of sequences with two and three puppet jumps. They looked significantly longer toward the test sequence that was novel in number, suggesting that they could discriminate number of events.

In light of evidence that infants use spatial extent in other quantitative tasks, these experiments using event sequences take on increased theoretical significance. In short, they may provide the only evidence that infants can detect changes in discrete number. As such, there is a clear need to replicate these findings and carefully rule out any confounding variables. For example, perceptual research has demonstrated that even newborns are highly sensitive to changes in rhythm (e.g., Dermany, McKenzie, & Vurpillot, 1977; Gibson, 1969). It is possible that responses in Wynn's (1996) experiment are based on the change in rhythm from two to three events, rather than the change in number per se. This outcome would be consistent with the proposal that people and animals can represent quantities in terms of temporal pattern matching or "rhythmic subitizing" (Davis & Perusse, 1988; vonGlasersfeld, 1982). Davis and Perusse illustrated this idea with the song "Deck the Halls" for which people can sing the correct number of "Fa La Las" without knowing the cardinal number of them.

If it is determined that infants represent event sets in terms of discrete number, then these results indicate that infants process these sets differently from visual collections of objects. One possibility is that estimating amount of spatial extent is less effortful; therefore, infants do so whenever possible. When they cannot estimate area, as in the case of event sequences, they may be forced to apply a more effortful enumeration mechanism. Another possibility is that the mechanism infants use to enumerate events applies only to sequential sets. In this case, infants would be unable to enumerate static sets regardless of which process was more effortful. Either way, our results indicate that infants do not use number to quantify visual sets of objects. Instead, this type of quantification is rooted in estimates of overall amount.

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