Research Report

NUMBER VERSUS CONTOUR LENGTH IN INFANTS' DISCRIMINATION OF SMALL VISUAL SETS

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Abstract—*This study examined infants' use of contour length in number discrimination tasks. We systematically varied number and contour length in a visual habituation experiment in order to separate these two variables. Sixteen 6- to 8-month-old infants were habituated to displays of either two or three black squares on a page. They were then tested with alternating displays of either a familiar number of squares with a novel contour length or a novel number of squares with a familiar contour length. Infants dishabituated to the display that changed in contour length, but not to the display that changed in number. We conclude that infants base their discriminations on contour length or some other continuous variable that correlates with it, rather than on number.*

Research over the past several decades has led some investigators to conclude that infants have sophisticated numerical abilities. For example, Gelman and Brenneman (1994) proposed that infants enumerate small sets by assigning a tag to each item in a particular order, so that the last tag represents the cardinal value of the set. This is tantamount to counting, but without verbal count words. Wynn (1996) has argued that infants possess abstract numerical abilities, claiming that the enumeration mechanism used by infants "does not operate over low-level perceptual information" (p. 169). Similarly, Starkey (1992) claimed that infants not only extract numerical information, but can also engage in computation and numerical reasoning. In short, number is seen as a privileged domain in which numerical information is a particularly salient property and number concepts develop relatively easily (Gelman, 1991; Wynn, 1995, 1997).

Support for these conclusions comes in part from the robust finding that infants can discriminate between small sets (Antell & Keating, 1983; Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1990; Strauss & Curtis, 1981). In these studies, infants were habituated to one set size (e.g., 2) and then shown a novel set size (e.g., 3). Infants looked at the novel set size significantly longer than the last habituation trial, suggesting that they could discriminate between small numbers of objects. However, several continuous variables were correlated with number in these displays, including brightness, area, mass, and contour length. Therefore, as other researchers have argued, it is possible that infants in habituation experiments react to changes in one of these continuous variables rather than to number per se (Feigenson & Spelke, 1998; Huttenlocher, 1994).

It may seem that this issue has already been resolved. Previous investigators recognized that number correlated with other variables and attempted to control for this by varying the habituation and test displays. However, these variations did not rule out the use of continuous variables completely. For example, Starkey and Cooper (1980) used linear arrays of dots as their stimuli. In these arrays, continuous variables such as area and contour length would still be correlated with number, and would change only with the addition or subtraction of a dot. In order to remove this confound, Starkey and Cooper compared infants' performance in a small-number condition (2 vs. 3) with their performance in a large-number condition (4 vs. 6). Starkey and Cooper reasoned that if infants were responding on the basis of continuous quantity, dishabituation would occur in both conditions because the proportionate difference was the same. Instead, they found that discrimination occurred only in the small-number condition, so it appeared that the infants must have been discriminating on the basis of discrete number. However, there is another reason that infants might fail to discriminate between large sets even though they attend to continuous quantity. McCall and Kagan (1967) found that infants detected changes in contour length only until the displays became too complex. Thus, it is possible that infants do use contour length but failed to discriminate in Starkey and Cooper's large-number condition because the displays were too complex.

Another approach to teasing apart these alternatives has been to use displays of items that vary in size (Starkey et al., 1990; Strauss & Curtis, 1981). For example, Starkey et al. (1990) tested infants with pictures of household objects that randomly differed in size. However, this manipulation does not provide an adequate control because variables like contour length tend to covary with number unless they are explicitly controlled. Furthermore, the density and size of the pictures were limited so that each picture could fit into a certain-sized space in the display. This consideration suggests that all the objects, regardless of actual size, were displayed at roughly the same size. Thus, the items would also have been similar in contour length.

Feigenson and Spelke (1998) recently pitted number against continuous quantity in a habituation study. In one condition, they habituated infants to one large three-dimensional object. At test, they measured looking time toward one small object or two small objects. In a second condition, infants were habituated to two small objects and then tested on one or two big objects. Infants dishabituated to both displays in both conditions. That is, they reacted to both a change in number and a change in mass, although the effect was much stronger for mass. Once again, though, it is unclear whether mass was systematically varied so that the mass of one large object was the same as the mass of the two smaller ones. If not, then the significant effect in the number condition might have been due to a change in mass.

In the present study, we varied continuous amount systematically within set size to examine whether infants' performance in number habituation studies is based on continuous quantity rather than discrete number. We focused specifically on contour length as the continuous variable because research in perceptual development confirms that infants are highly sensitive to contour length (e.g., Karmel, 1969; McCall & Kagan, 1967; Pipp & Haith, 1984). Contour length is the sum total of the perimeters of the individual objects in the set (e.g., a display with four squares whose sides are 2 cm long would have 32 cm total contour length). Note that this variable is not the same as the perimeter of a box drawn around all of the objects together, which is what has

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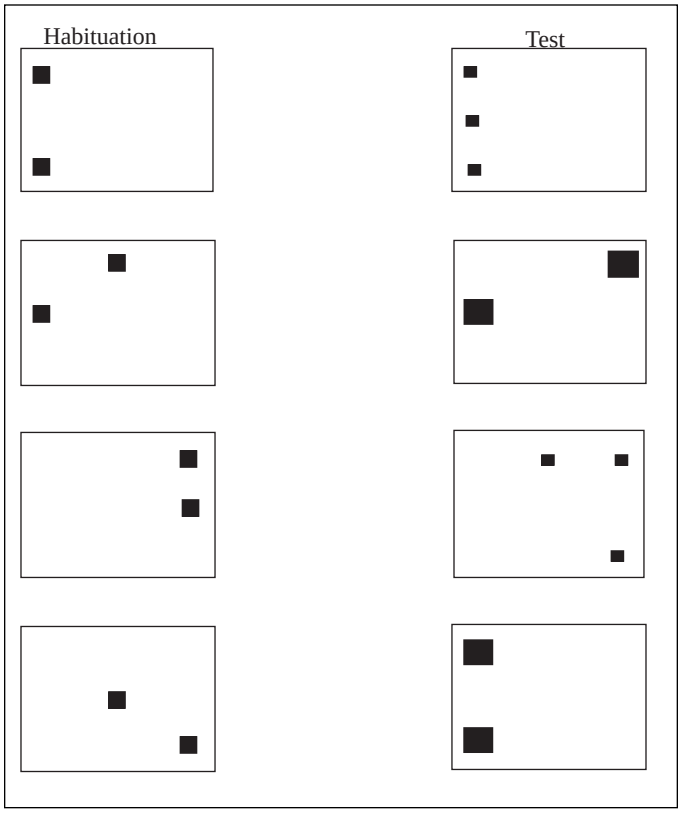

Fig. 1. Sample habituation and test stimuli.

been varied by other researchers. Changes in contour length are based on variations in the sizes of the objects themselves, not spacing.

We habituated infants to visual displays of either two or three squares. We then presented two alternating test displays. In one display, the number of squares was familiar, but the total contour length of the squares varied, so that it equaled the amount of contour length there would have been had we added or subtracted a square (see Fig. 1). In the other test display, the number of squares changed but the total contour length was exactly the same as it was in the habituation trials. We predicted that if infants attended to contour length, they would dishabituate to the familiar-number/different-contour-length display. If they attended to number, they would dishabituate to the different-number/familiar-contour-length display.

METHOD

Subjects

Subjects were 16 healthy, full-term babies (9 female, 7 male) 6 to 8 months of age (mean = 6.8 months, range: 5.86–7.73). One additional infant was excluded because of fussiness. Infants were recruited through local birth announcements and were given a small gift for participating.

Design

Half the infants were habituated to two squares, and half were habituated to three. Following the habituation trials, infants were presented with eight test trials that alternated between changes in number and changes in contour length. Half the infants in each group saw the display differing in number first, and half saw the display differing in contour length first. Approximately equal numbers of boys and girls participated in each condition.

Contour length was measured as the total perimeter of items in the display. For example, in one condition, infants were habituated to two squares of 16 cm total contour length (i.e., 8 cm per square). The test trials were 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). This manipulation is analogous to the contour-length differences in previous studies in which number and contour length were confounded.

Apparatus

Infants sat in an infant seat located 30 cm from the display. Black curtains surrounded the room. Displays were computer-generated drawings of black squares, mounted on white foam board measuring 21.5 × 28 cm. Stimuli were slid in and out of the display opening (a hole cut in the black curtain) from behind. A stopper was attached to the far end of the opening to ensure that display cards were placed at the same location within the opening at every trial. One experimenter slid the cards in and out of the display opening, and 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 without the knowledge of the second experimenter. The experimenter who recorded looking time was unaware of what the baby was seeing.

Procedure

Infants were placed in the infant seat on a table facing the display. Parents sat directly behind the table and wore sunglasses painted black so they could not see the displays. Parents were told not to interact with their infants unless the infants became upset.

Infants were shown up to 16 habituation trials of the same number and contour length. The squares on these cards varied in position exactly as in the visual stimuli used by Starkey et al. (1990). We used the standard habituation criterion and procedures used by previous number researchers (e.g., Starkey et al., 1990). Trials began as soon as the infant first fixated on the display and lasted for 10 s. Infants were shown habituation displays until the average looking time for 3 consecutive trials was half the average looking time for the first 3 habituation trials. Immediately following the last habituation trial, infants were shown 8 alternating test trials.

RESULTS

A coder blind to the experimental conditions measured looking time from the videotapes of 25% of the sessions. Interrater agreement between this coding and the on-line recordings of the first experimenter was high (.91), so the on-line recordings were used in all subsequent analyses.

Paired *t* tests comparing looking time on the first three habituation trials and the last three habituation trials revealed a significant difference, $t(15) = 5.52$, $p < .0001$, which indicates that babies did habituate. All infants habituated, and the average number of trials to habituation was 11 ($SE = 0.97$). The crucial test was whether infants dishabituated to the change in contour length or the change in number. We conducted paired *t* tests comparing looking time on the last habituation trial with looking time on the first of each type of test trial (see Fig. 2). Infants' looking time increased significantly on the test trials with a change in contour length, $t(15) = 3.58$, $p < .01$, but not on the test trials with a change in number, $t(15) = 0.51$, n.s.

Thirteen of the 16 infants looked longer at the contour-length change than at the number change ($p < .01$, binomial test), so the significant difference found for the group was not due to extreme differences in looking time for just a few infants. The remaining 3 infants looked longer at the change in number. Note, however, that it is not possible to test whether these looking preferences are significant because of the limited number of trials per individual. That is, individual infants could have dishabituated to number only, contour length only, neither one, or both.

DISCUSSION

The infants in this study dishabituated to a change in contour length when number remained constant, and did not dishabituate to number when contour length remained constant. Our results clearly indicate that when these features are separated, infants attend to contour length, rather than number, to discriminate between sets. However, because contour length is correlated with total area, brightness, and size, it could be any or all of these variables that affect infants' looking behavior in this task.

These findings suggest a reinterpretation of previous results regarding infants' discrimination of small visual sets. Infants from birth to 12 months of age have dishabituated to changes in number when presented with static visual displays (Antell & Keating, 1983; Starkey & Cooper, 1980; Starkey et al., 1990; Strauss & Curtis, 1981). These results have been interpreted as demonstrating infants' ability to individuate sets and detect changes in discrete number. However, in all those studies, variables related to continuous quantity covaried with number. The current findings indicate that when these variables are properly separated, infants attend to continuous quantity instead of number.

The same result has been found for infant calculation. Wynn (1992) presented addition and subtraction problems to 5-month-olds using puppets and a screen. For example, infants saw one puppet placed behind a screen and then saw a second puppet placed behind the same screen. The screen dropped and the infants saw either one or two puppets. Infants looked longer at the incorrect solution, which led Wynn to conclude that they perform precise calculations over discrete number. However, Feigenson and Spelke (1998) recently reported that infants use continuous quantity in this task instead of number. They used Wynn's procedure but manipulated the size of the puppets to control for mass. For example, two small puppets were placed behind a screen. When the screen dropped, infants saw either one or two large puppets. Infants looked longer toward an unexpected change in mass, not number. Thus, the present finding that infants attend to continuous quantity rather than discrete number also extends to calculation.

These results involving infants' use of continuous variables suggest two possible interpretations. One is that infants cannot represent discrete number separate from correlated perceptual variables. This possibility is consistent with recent findings that have raised doubts about the basis of infants' behavior in other numerical tasks, such as auditory-visual matching (Mix, Levine, & Huttenlocher, 1997; Moore, Benenson, Reznick, Peterson, & Kagan, 1987). An alternative interpretation is that infants are capable of discriminating on the basis of number if necessary, but prefer to use contour length if possible. This interpretation is consistent with Wynn's (1996) finding that infants discriminate action sequences that differ in number. Her results might show that infants can count or otherwise represent number, but do so only when other information, such as contour length, is unavailable.

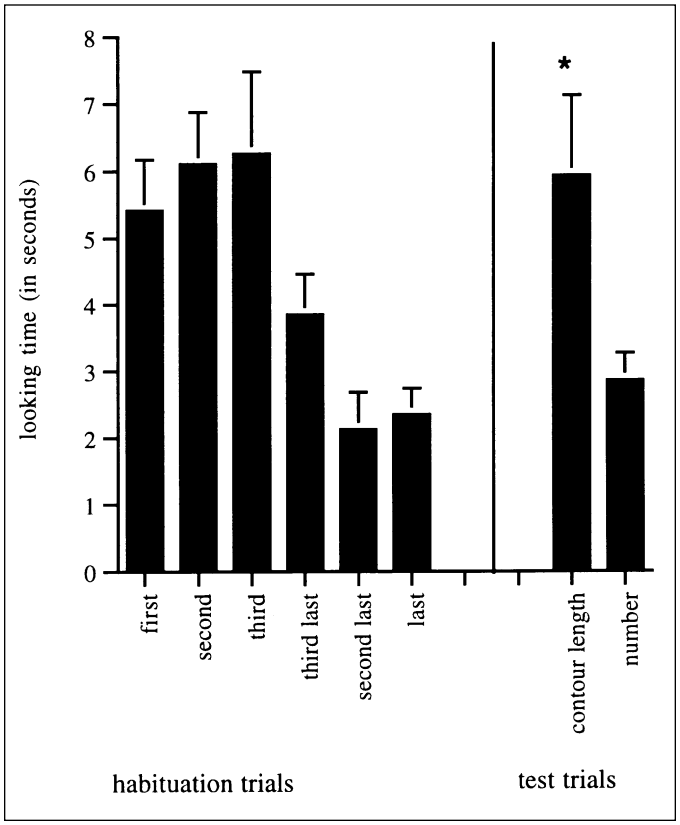

Fig. 2. Mean looking times at habituation trials and test trials (change in contour length vs. change in number). Error bars represent standard errors of the mean. *$p < .01$.

The present findings cannot distinguish between these possible interpretations. However, under either interpretation, our results highlight the importance of perception in infants' numerical development. Even under the weaker interpretation that infants can use number if necessary, our results show that infants prefer to discriminate on the basis of basic perceptual variables, rather than relying on abstract cognitive knowledge. The present finding indicates that the importance of some of these perceptual variables may have been underestimated in previous studies of infants' numerical abilities.

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