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Number trumps area for 7-month-old infants

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Abstract

Over the past few decades there has been extensive debate as to whether humans represent number abstractly and if so, whether perceptual features of a set such as cumulative surface area or contour length are extracted more readily from the external world than number. Here we show that 7-month-old infants are sensitive to smaller ratio changes in number than cumulative area when each variable is tested separately and that infants prefer to look at number changes compared to area changes when the two variables are directly pitted against each other. Our results provide strong evidence that number is a more salient dimension to young infants than cumulative surface area and that infants' ability to discriminate sets based on number is more finely tuned than their ability to discriminate sets based on cumulative surface area.

Keywords

numerical cognition; infant numerical abilities; number discrimination; area discrimination

There has been a long-standing debate as to whether infants and young children represent the numerosity of a set of items or instead attend to cumulative contour length or surface area and only later learn to attend to number (Mix, Huttenlocher, & Levine, 2002; Piaget, 1952). A prevalent assumption has been that it is easier to extract and represent perceptual information compared to numerical information. Importantly, Clearfield and Mix (1999, 2001) argued that infants are only sensitive to changes in contour length or area, but not to number changes, under conditions in which these variables are confounded and subsequently pitted against each other (see also Feigenson, Carey, & Spelke, 2002). They interpret this finding to suggest that infants first develop a general sense of amount rather than a sense for number (see Mix et al., 2002, for a review).

In contrast, Cordes and Brannon (2009) showed that infants extract numerical *and* non-numerical information from sets of items when the numbers are small (<4) but that they extract numerical information at the expense of cumulative area when the set sizes are large. Furthermore, using a between-subject habituation paradigm they showed that 6-month-old infants successfully discriminate 7 from 21 circles (1:3 ratio in number) but fail to discriminate the same 1:3 ratio in cumulative surface area both with small and large set sizes (Cordes & Brannon, 2008). In fact, infants required a 1:4-ratio change in cumulative surface area to successfully discriminate sets. These findings suggest that young infants are capable of discriminating area but that number discriminations are actually easier for them.

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In the present study, we used a change detection paradigm to directly test whether infants find changes in the numerosity or the area of a set to be more salient (M. E. Libertus & Brannon, 2010; Ross-Sheehy, Oakes, & Luck, 2003). Our results replicate the findings by Cordes and Brannon (2008) demonstrating that infants are more sensitive to changes in the numerosity of a set compared to the cumulative area of a set and extend those findings to show that infants prefer to look at noticeable numerical changes compared to noticeable area changes when the two variables are in direct competition for their attention.

Method

Participants

Ninety-six 7-month-old infants (mean age = 209.28 days, SD = 8.83 days; 43 females) participated, 16 in each of six conditions. Data from 15 additional infants were excluded due to fussiness (n = 12) or not looking to both screens during at least one of the trials (n = 3). Data from three additional infants were excluded because their preference scores (see below) were more than two standard deviations above or below the mean of their respective conditions. Parents gave written informed consent to a protocol approved by the local Institutional Review Board.

Design

Infants were randomly assigned to one of six conditions[1]. In all six conditions infants were shown two streams of images, one on each of two peripheral monitors (see Figure 1). In the first three conditions, infants were shown one stream that contained images that alternated between two different values of cumulative surface area while holding number constant and another stream that contained images that held both number and area constant. In Condition 1, area changed by a 1:3 ratio, in Condition 2, area changed by a 1:5 ratio, and in Condition 3 area changed by a 1:10 ratio. In the remaining three conditions, changes in number and area were pitted against each other. One stream alternated between two numerosities while holding cumulative surface area constant whereas the other stream alternated between two different values of cumulative surface area while holding number constant. In Condition 4, both number and area changed by the same 1:3 ratio. In Condition 5, number changed by a 1:3 ratio and area changed by a 1:5 ratio. Finally, in Condition 6 number changed by a 1:3 ratio and area changed by a 1:10 ratio. In all conditions, the images in both streams varied in the configurations of the elements in the sets such that even a no-change condition contained some change, namely in the arrangement of the elements.

Stimuli

In all conditions, the visual streams consisted of images containing black circles on a white background that were presented for 500 ms followed by 300 ms of blank screen. For all conditions with a 1:3-ratio change in number, arrays contained 6 and 18 circles while cumulative surface area remained constant (12 cm^2). Thus, number and individual element size changed threefold. In the area-change streams, 12 circles either alternated in cumulative surface area between 6 cm^2 and 18 cm^2 (1:3), 5 cm^2 and 25 cm^2 (1:5) or 2.28 cm^2 and 22.8 cm^2 (1:10). Thus, individual element size and cumulative surface area changed three-, five- or ten-fold. The no-change streams always contained 12 circles and for half the infants the cumulative surface area was equal to the larger area and for the other half it was equal to the smaller area. Thus, infants could have used cumulative surface area or individual element size as a cue to differentiate between the area-change and no-change streams. However, when area and number changes were directly compared, individual element size changed in

[1]Conditions 2 and 5 were conducted after the other four conditions in response to suggestions from reviewers.

both image streams. Density was manipulated orthogonally such that half of the images across both images streams had equal density.

Procedure

Infants sat in a high chair or on a parent's lap approximately 105 cm away from the middle of three 17-inch computer screens. The distance between the center of the middle screen and the center of the peripheral monitors was 55 cm. At the beginning of each trial, participants were presented with a colorful attractor on the middle screen. The experimenter manually initiated each trial when the infant looked at the attractor. Each trial lasted 60 seconds and each infant was tested with four trials. The image streams alternated sides between trials and the order was counterbalanced between infants. In addition, half of the infants in the conditions where a changing image stream was paired with a non-changing stream were presented with a non-changing image stream that contained the larger number or cumulative surface area, the other half were presented with the smaller value.

Infants' looking behavior was digitally recorded for later off-line coding. An experienced, naive observer coded infants' looking behavior to the screens using a custom-made coding program written in RealBasic (K. Libertus, 2008). A second observer coded 25% of all participants in each condition and reliability between the two observers was extremely high ($r = 0.96 – r = 0.99$).

Data analysis

We analyzed the proportion of time each infant spent looking at each of the two image streams as a function of each infant's total looking behavior to both screens. This measure normalized the data and thus eliminated individual differences in overall attention to the stimuli. Preference scores for Conditions 1, 2, and 3, which contrasted infants' preference for an area-change stream against a no-change stream, are reported as a preference for the no-change stream (i.e., % looking time to the no-change stream across the four trials minus % looking at the area-change stream). Preference scores for Conditions 4, 5, and 6, where number and area changes were directly pitted against each other, are reported as preference for the number-change stream (i.e., % looking time to the number-change stream across the four trials minus % looking at the area-change stream). Thus, a negative score in each of the six conditions indicates a preference for the area-change stream. For each condition, we performed a one-sample t-test comparing preference scores to zero and binomial statistics on the number of infants showing positive or negative preference scores.

Results

Our main finding was that infants preferred to look at changes in the number compared to changes in the area of an array when noticeable changes in each were directly compared. Conditions 1–3 compared a stream with area changes to a second stream, which held both number and area constant. Figure 2 shows that infants in Condition 1 showed no preference for a 1:3 ratio change in cumulative surface area compared to no change ($t(15)=0.44$, $p=0.66$) and only 6 out of 16 infants looked longer to the area-changing stream ($p=0.45$, binomial). In contrast in Conditions 2 and 3, infants looked significantly longer to the change in area compared to the stream which held both number and area constant (1:5 ratio: $t(15)=3.62$, $p<0.01$; 1:10 ratio: $t(15)=4.52$, $p<0.001$). In Condition 2, 12 out of 16 infants showed this preference ($p<0.05$) and in Condition 3, 13 out of 16 infants showed this preference ($p<0.05$).

Conditions 4–6 tested infants' preference for one stream that changed in number with a second stream that changed in area. In Condition 4, infants showed a significant preference for the number-change stream when a 1:3-ratio change in number was directly pitted against a 1:3-ratio change in area ($t(15)=2.1$, $p=0.05$) and 13 out of 16 infants looked longer to the number-change stream compared to the area-change stream ($p<0.05$).

Similarly, in Condition 5, where a 1:3-ratio change in number was directly pitted against a 1:5-ratio change in area, infants showed a significant preference for the number-change stream ($t(15)=2.7$, $p=0.02$). Thirteen out of 16 infants looked longer to the number-change stream compared to the area-change stream ($p<0.05$). This condition is critical because it demonstrates that infants prefer numerical changes to area changes even when the cumulative area changes are comfortably within their range of discrimination (Cordes & Brannon, 2008). An analysis comparing looking times in Condition 2 of the present report (1:5-ratio change in area vs. no change) with the same ratio change for number from a previous report (1:3-ratio change in number vs. no change from M. E. Libertus & Brannon, 2010) revealed no difference ($t(30)=1.03$, $p=0.31$) suggesting that when presented alone a 1:3-ratio change in number and a 1:5-ratio change in area are equally noticeable to infants.

Finally, in Condition 6 a 1:3-ratio change in number was pitted against a 1:10-ratio change in area. Despite the dramatically larger change in area compared to number, preference scores were not significantly different from chance ($t(15)=-1.42$, $p=0.18$) and only 10 out of 16 infants looked longer to the area-change stream ($p=0.45$). This finding should be interpreted in light of the large preference scores elicited to the 1:10-ratio change in area (Cond. 3) when contrasted with no changes in area or number. In fact the 1:10-ratio change (Cond. 3) elicited a significantly greater preference score than the 1:3-ratio change in number vs no change from a previous study (M. E. Libertus & Brannon, 2010; $t(30)=-2.66$, $p=0.01$). Nevertheless, the 1:10 ratio change in area was not dramatic enough to reverse a number-change preference.

Discussion

The results of the present study show that infants preferred to look at images that varied in number compared to images that varied in area by the same ratio (Condition 4) or by different ratios when both were well within their range of discrimination (Condition 5). These findings suggest that numerical changes are more salient and easier to detect than changes in cumulative area. Even when images that varied in cumulative surface area by a 1:10 ratio were contrasted with images that varied in number only by a 1:3 ratio (Condition 6), this was still insufficient to reverse infants' preferences in favor of area and instead merely eliminated the number preference. This is quite surprising given that infants' preference scores for a 1:10-ratio change in area when contrasted against no change were significantly higher than their preference scores for a 1:3-ratio change in number pitted against no change.

We also found that infants were unable to detect a 1:3-ratio change in cumulative surface area (Condition 1) but successfully detected a 1:5-ratio (Condition 2) and a 1:10-ratio change in cumulative surface area (Condition 3). These results are consistent with previous findings by Cordes and Brannon (2008) where a 1:4-ratio change in cumulative surface area was necessary to produce dishabituation in 7-month-olds and infants failed to dishabituate to a 1:2- or 1:3-ratio change in cumulative surface area. Collectively, these results refute the idea that cumulative surface area is easier to extract for infants than numerical information (Clearfield & Mix, 1999, 2001; Mix et al., 2002). Instead, number appears to be the more salient dimension for infants and their numerical discrimination is actually more finely tuned than discriminations of cumulative surface area.

It is important to note that the stimuli in the area-change stream were constructed such that infants could use either the surface area of a single circle or the cumulative surface area of all circles as a basis for their area discrimination because both dimensions varied by the same ratio. Given that six-month-old infants are able to discriminate between different sizes of a single element when the difference is as small as a 1:2 ratio (Brannon, Lutz, & Cordes, 2006), why did the 7-month-old infants in our study fail to use the change in size of a single circle as a cue for detecting the change in cumulative area? A recent study by Cordes and Brannon (2011) directly addressed this question. They found that infants' ability to detect changes in area is less fine-tuned when there are multiple elements present compared to a single element presented. Specifically 7-month-old infants needed at least a 1:4-ratio change in the size of each circle when multiple objects were presented simultaneously. In support of these previous findings, our results also suggest that infants do not represent the size of a single element very precisely when they encounter large numbers of elements.

Given that infants did successfully detect the 1:5-ratio and 1:10-ratio area changes in Conditions 2 and 3 our results demonstrate that they are in principle capable of extracting cumulative area information or attending to the change in size of a single element in a set and make discriminations based on this information. Thus, it is not impossible for infants to detect area changes such as those presented in Conditions 5 and 6. Instead, our results suggest that these changes are less salient than number changes.

In sum, our results support two main conclusions. The first finding is that 7-month-old infants appear to be sensitive to smaller ratio changes in number than cumulative area when each variable is tested separately (Cordes & Brannon, 2008, 2009; M. E. Libertus & Brannon, 2010; Starr, Libertus, & Brannon, in press). The second finding is that infants prefer to look at number changes compared to area changes when the two variables are directly pitted against each other and are both within the discriminable range for this age group. Future studies may use this paradigm to compare the relative salience of number with other perceptual dimensions such as contour length or density.

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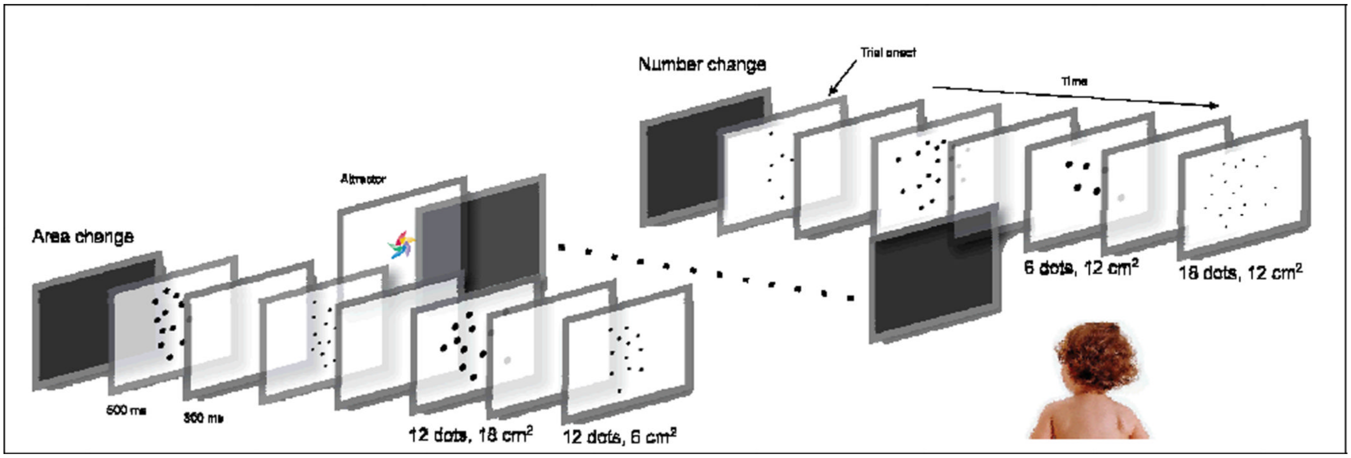

Figure 1.
Experimental design: Infants were presented with two simultaneous image streams on peripheral screens. In the condition depicted here, one of the image streams alternated between images with two different numbers of dots (6 and 18, 1:3 ratio) while cumulative surface area remained constant (number-change stream), while the other image stream alternated between images with two different cumulative surface area values (6 and 18 cm^2, 1:3 ratio) but stayed constant in number (area-change stream).

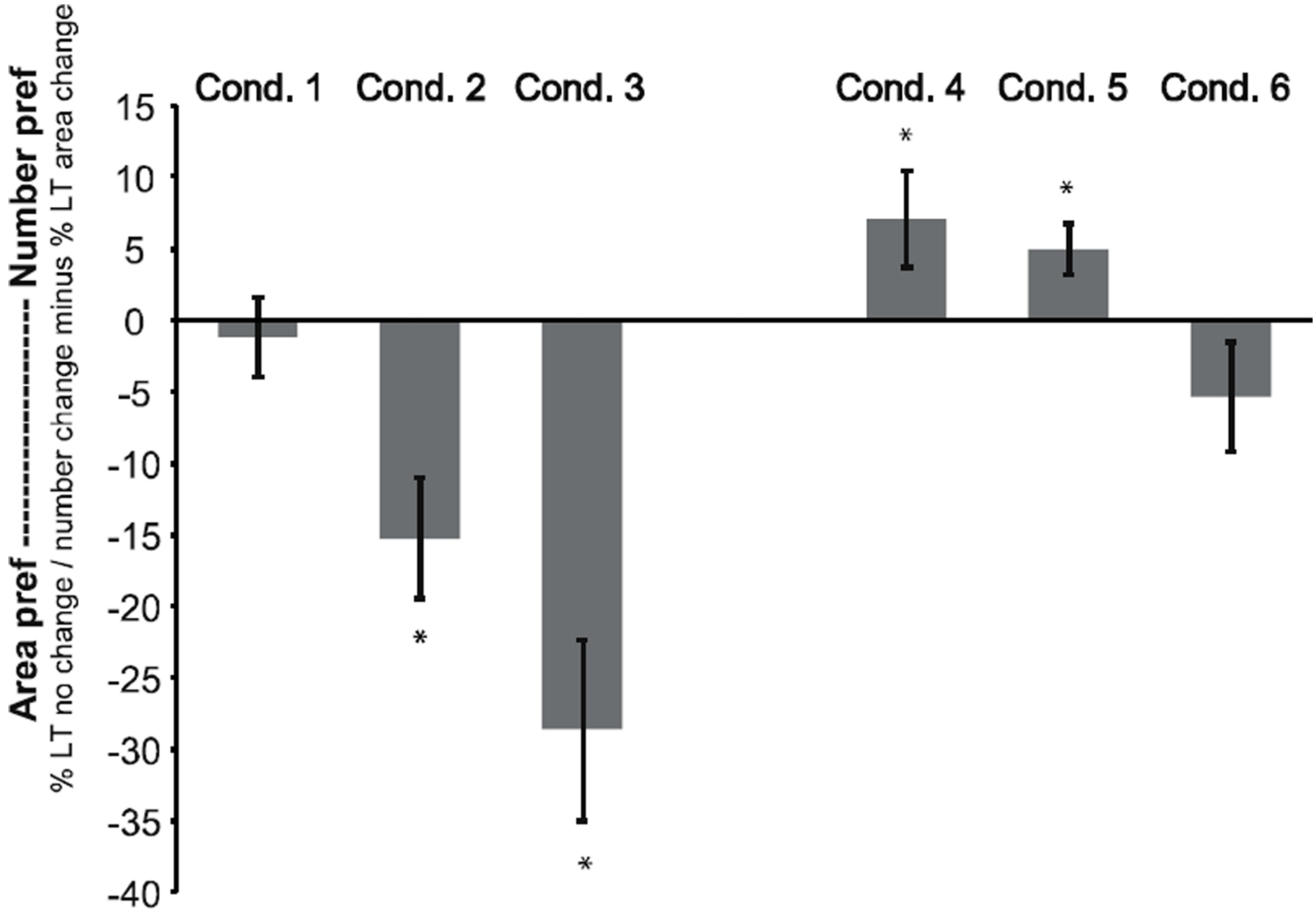

Figure 2.

Preference scores for number and area changes. No significant differences in looking times were found when a 1:3-ratio change in area was pitted against no change (Cond. 1). However, infants looked significantly longer when a 1:5- or 1:10-ratio change in area was pitted against no change (Cond. 2 & 3 respectively). Critically, infants looked significantly longer when a 1:3-ratio change in number was pitted against a 1:3- or 1:5-ratio change in number (Cond. 4 & 5 respectively). No significant differences in looking times were found when a 1:3-ratio change in number was pitted against a 1:10-ratio change in area (Cond. 6).