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Brief report

Number discrimination in 10-month-old infants

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Two experiments investigated developmental changes in large number discrimination with visual-spatial arrays. Previous studies found that 6-month-old infants were able to discriminate arrays that differ by a ratio of 1:2 but not 2:3. We found that by 10 months, infants were able to reliably discriminate 8 from 12 elements (2:3) but not 8 from 10 elements (4:5). Thus, number discrimination improves in precision during the first year, and these findings converge with studies using auditory stimuli.

Human adults and non-human animals possess a 'number sense' that allows them to discriminate and estimate numerosities larger than three. Several recent studies have focused on large number discrimination in prelinguistic human infants (e.g. Brannon, Abbot, & Lutz, 2004; Lipton & Spelke, 2003, 2005; Xu, 2003a, 2003b; Xu & Spelke, 2000; Xu, Spelke, & Goddard, 2005). At 6 months of age, infants are able to discriminate numerosities that differ by a 1:2 ratio (4 versus 8, 8 versus 16 and 16 versus 32) but not those differ by a 2:3 ratio (4 versus 6, 8 versus 12 and 16 versus 24) with both visual-spatial arrays and auditory-temporal sequences. In these studies, a host of continuous variables that covary with number were controlled for, (e.g. total contour length, total filled area, average density of elements, average brightness, display size, element size, duration of individual sounds, duration of sequences, etc.). A growing consensus suggests that although infants may be tracking individual objects when viewing small number of elements (see Carey & Xu, 2001; Feigenson, Carey, & Hauser, 2002; Feigenson, Carey, & Spelke, 2002; Scholl, 2001; Simon, 1997; Xu, 2003a, 2003b; among others for detailed discussions), there is a separate system for large number estimation that is shared by human infants, human adults and non-human animals (see Barth, Kanwisher, & Spelke, 2003; Cordes, Gelman, Gallistel, & Whalen, 2001; Dehaene, 1997; Feigenson, Dehaene, & Spelke, 2004; Gallistel & Gelman, 2001; Mix, Huttenlocher, & Levine, 2002; Wynn, 1998; Xu, 2003a, 2003b; Xu & Spelke, 2000; Xu *et al.*, 2005).

Since young infants are only able to discriminate numerosities that differ in ratio between 3:2 and 2:1, the question of developmental change immediately arises. Adults

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can discriminate large arrays of filled discs with a ratio of 1:1.15 (Van Oeffelen & Vos, 1982), much more precisely than infants. When can infants discriminate numerosities with a ratio of 3:2 or smaller with visual-spatial arrays? Studies by Lipton and Spelke (2003, 2005) found that by about 9 months, infants were able to discriminate 8 from 12 sounds but not 8 from 10 sounds. Does the same developmental change occur with visual-spatial arrays? The current experiments attempt to answer this question.

Experiment 1 investigated whether 10-month-old infants[1] discriminate between 8 elements and 12 elements (2:3 ratio). Experiment 2 investigated whether 10-month-old infants discriminate between 8 elements and 10 elements (4:5 ratio).

EXPERIMENT 1

Method

Participants

Participants in the study were 24 full term infants (mean age 10 months 5 days, ranging from 9 months 25 days to 10 months 30 days; half girls, half boys). There were four additional infants who were excluded from the sample because of fussiness (2) and parental interference (2).

Apparatus

Infants sat on a parent's lap about 60 cm from a computer screen that provided the only source of illumination in the room. The screen was placed at the infant's gaze level. Parents were asked to close their eyes or fixate on their infant's shoulders but not to look at the screen. Parents were also instructed not to talk or direct the infant's attention in any way. Video-recordings were made to assess parental compliance.

The computer screen was surrounded by black panels that occluded the back of the room. The black panels also provided 'peepholes' for the experimenters to monitor the infant's behaviour. An observer sat behind the panels and recorded looking times by pressing a button that was connected to a computer. The observer recorded looking time whenever the reflection of the screen was visible on the infant's eyes.

Design

Equal numbers of male and female participants were habituated to displays with 8 or 12 elements. Following habituation, infants were presented with six test trials in which three pairs of displays with 8 elements and 12 elements were shown alternately, in a counterbalanced order.

Stimuli

Displays were constructed using the same software that was used by Xu and Spelke (2000) and the displays for this study had the same dimensions as those used in their 8- versus 12-element experiment. The only difference was that the displays were presented on a 12-inch computer monitor rather than on a cardboard background.

Displays consisted of filled disks. Each set of six habituation displays consisted of 8 or 12 disks that varied in size and position across trials (see Figure 1). The less numerous displays

[1] *These experiments were conducted concurrently with the studies reported in Lipton and Spelke (2003). It was coincidental that we tested 10-month-old infants whereas they tested 9-month-old infants.*

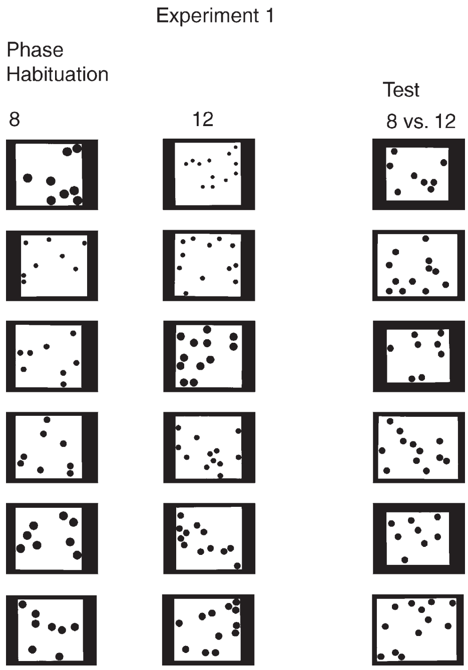

Figure 1. Schematic representation of the displays in Experiment 1.

therefore had a third of the element density. The dot positions were chosen randomly from a matrix; displays that looked too cluttered were discarded. Each habituation display measured 20 × 19 cm. The mean disk size was 2.24 cm in diameter (range 1.41–2.82 cm) for the 8-element displays and 1.82 cm (range 1.14–2.44 cm) for the 12-element displays. Element densities in the 8- and 12-disk displays were .021 and .031 element/cm^2, respectively.

For the test displays, element density was equated and equidistant from the habituation densities. The display size was 16 × 19 cm for the 8-element displays and 19 × 24 cm for the 12-element displays (see Figure 1). The individual elements were 2 cm in diameter and the average density was .026 element/cm^2 for all test displays.

Procedure

A set of six habituation displays was presented in a randomly repeating order for each infant. Participants viewed one display on each trial, which began with a minimum of 0.5-second look at the display and ended with the first 2-second look away. Habituation criterion was met when the infant's looking time declined by 50% or more over three consecutive trials, relative to the total looking time of the first three trials that summed to at least 12 seconds. The maximum number of habituation trials was 14. After habituation, infants were shown the six test displays following the same procedure and alternating between the two numerosities.

Results

A 2 × 2 × 3 ANOVA examining the effect of habituation condition (8 or 12), test trial (old or new number) and test trial pair on looking times revealed a significant main effect of test trial type, $F(1,\ 22) = 17.905, p < .001$ (Figure 2). The infants (20 out of 24) looked longer at the new number displays ($M = 6.0$ seconds, $SD = 4.1$) than at the old

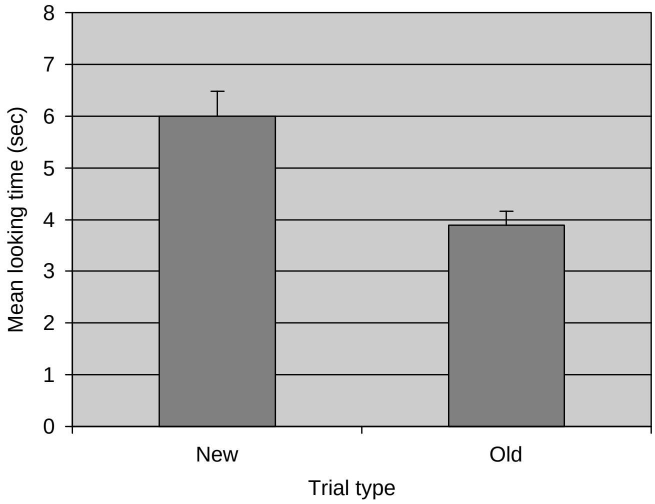

Figure 2. Mean looking times for new versus old numbers in Experiment 1.

number displays ($M = 3.9$ seconds, $SD = 2.4$). There were no other statistically reliable main effects or interactions.

Discussion

Ten-month-old infants distinguished between 8- and 12-element displays when continuous variables such as total area, average density of the elements, average brightness of the displays, element size and display size were controlled. Although 6-month-old infants were not able to discriminate 8 from 12 elements (Xu & Spelke, 2000; Lipton & Spelke, 2003), 9- and 10-month-old infants are able to with both visual-spatial and auditory-temporal arrays (Lipton & Spelke, 2003, 2005). These results suggest that as infants get older, they are able to discriminate between displays that differ in smaller ratios. In Experiment 2, we asked what the ratio limit is for 10-month-old infants by investigating whether they can discriminate 8 elements from 10 elements (4:5 ratio).

EXPERIMENT 2

Method

The method was the same as in Experiment 1, except for the following.

Participants

There were 24 full-term infants who participated in the study (mean age 10 months 6 days, ranging from 9 months 29 days to 10 months 25 days; half girls, half boys); two additional infants were excluded from the sample because of fussiness.

Stimuli

Each habituation display measured 20 × 19 cm. The mean element size was 2.24 cm in diameter for the 8-element displays (same as in Experiment 1) and 2.0 cm in diameter for the 10-element displays. Element densities in the 8- and 10-element displays were .021 element/cm^2 and .026 element/cm^2, respectively.

For the test displays, element density was equated and equidistant from the habituation densities (.0235 element/cm^2) display height was 19 cm. The widths for the displays were 18.0 and 22.5 cm for the 8- and 10-dot displays, respectively. The disks were 2.12 cm in diameter and the average density was .0235 element/cm^2, for all test displays.

Results and discussion

A $2 \times 2 \times 3$ ANOVA examining the effect of habituation condition (8 or 10), test trial (old or new number) and test trial pair on looking times revealed no statistically reliable main effects or interactions. Infants looked about equally at the new and old number displays, $F(1, 22) = 1.338$, $p = .26$ (Figure 3). Consistent with the results in Lipton and Spelke (2003), 10-month-old infants failed to discriminate 8 from 10 elements in visual-spatial arrays.

An additional ANOVA compared the two experiments with experiment, old versus new number and trial pair as factors. There was a statistically reliable interaction between experiment and old versus new number, $F(1, 46) = 11.109$, $p < .05$.

GENERAL DISCUSSION

Two experiments investigated whether 10-month-old infants were able to discriminate numerosities with a ratio smaller than 2:1 in visual-spatial arrays. In Experiment 1, infants succeeded in discriminating 8 elements from 12 elements (2:3 ratio). In Experiment 2, infants failed to discriminte 8 elements from 10 elements (4:5 ratio).

These findings corroborate and extend the results of Lipton and Spelke (2003). Using auditory-temporal sequences, they found success with 9-month-old infants with a ratio of 2:3 but not 4:5.

These studies further our understanding of the development of number discrimination in infancy. The fact that we found similar developmental trajectories for visual-spatial arrays (Brannon *et al.*, 2004; Xu, 2003a, 2003b; Xu & Spelke, 2000; Xu *et al.*, 2005; present studies) and auditory-temporal sequences (Lipton & Spelke, 2003, 2005) is consistent with the thesis that a single underlying mechanism is responsible for generating abstract number representations (see Barth *et al.*, 2003; Gallistel, 1990, for evidence in adult humans and non-human animals). This mechanism is coarse and imprecise early in development (around 6 months of age) and it becomes increasingly

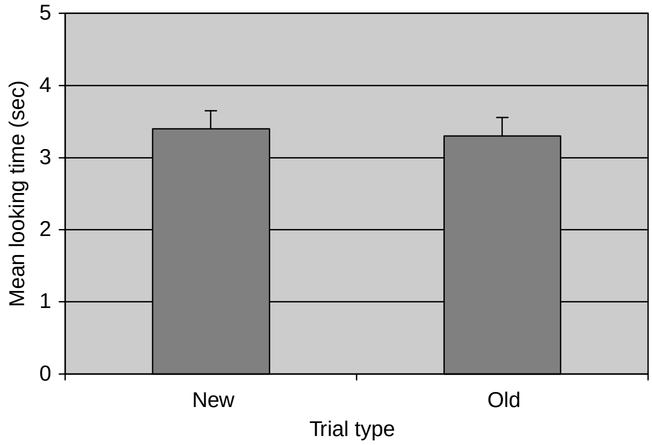

Figure 3. Mean looking times for new versus old numbers in Experiment 2.

more precise over the course of the first year (improvement by about 9 to 10 months). Such improvement precedes the onset of verbal counting by almost 2 years; therefore, it is unlikely to be influenced by language learning. Perhaps improvement in visual acuity in infants is responsible for the developmental course we witness here. Although these results are consistent with the idea that abstract number representations are present in infancy, further studies directly probing cross-modal transfer are necessary to provide more direct empirical evidence. Such studies are underway in our laboratories and others.

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