Hindawi Publishing Corporation
Education Research International
Volume 2012, Article ID 964052, 5 pages
doi:10.1155/2012/964052

Research Article

Small Number Discrimination in Early Human Development: The Case of One versus Three

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Received 13 March 2012; Revised 25 June 2012; Accepted 25 June 2012

Academic Editor: Jan Elen

The current study aims to investigate in infants the discrimination of the number set 1 versus 3. This number set has not been studied before within the field of early number discrimination. Participants were 16 full term 8-month-olds. They were assessed for their number discrimination ability with a computerized habituation task in combination with an eye tracking device as an accurate measure for looking time in infants. The stimuli (dots) were controlled for continuous variables. Attention was given to different approaches to analyse data retrieved from the habituation paradigm. The main results showed that 8-month-olds discriminated 1 from 3 dots by looking longer at a novel number after habituation to another number. This supports small number discrimination in infancy. Results retrieved through other analyse approaches are discussed.

1. Introduction

In the course of the last two decades, studies have revealed that preverbal children rely on an object-file system to process small numbers (<4) and an analogue magnitude system to process large ones (>3) [1, 2]. The first system enables a discrete and exact representation of a limited number of items [3, 4]. This concept of an object-file system originates from visual attention literature [5, 6] and proposes that for sets of three (or four) or less items, infants have an exact one-to-one correspondence representation of these items. This allows young children to make a precise discrimination between a number of objects in the small number range. The second system enables a less precise, approximate representation of a larger number of items [1]. Number discrimination within the second system is ratio dependent, according to Weber's law: discrimination becomes less precise with increasing numerosity and the ratio between numbers determines the ease of discrimination [7–10]. A crucial question for both systems, however, remains upon which variables the discrimination is based [11]. Some studies suggest that children use the discrete variable "number" [12, 13], whereas others believe that they rely on continuous variables such as the total occupied area of all the items together [14, 15]. Controlling for these continuous variables in stimuli is, therefore, essential to rule out that infants use these variables instead of the discrete variable "number" to discriminate number sets.

Tasks based on the habituation paradigm are frequently used to study number discrimination in very young children. In these tasks, children see a specific number of stimuli (e.g., dots) until they are habituated to it (or had a maximum number of habituation trials, mostly 14). Afterwards, they see, in alternating order, the same number and a new number. Longer looking time at the novel number or dishabituation [16] is considered to be an indication of discriminating between the given numbers [2, 17].

Various studies have investigated large number discrimination with this paradigm and have evidenced that 6-month-olds differentiate large numbers when the ratio is 1 : 4 as in 4 versus 16 [18], 1 : 3 as in 7 versus 21 [12] or 1 : 2 as in 4 versus 8, 8 versus 16 and 16 versus 32 [2, 13, 17–19]. Findings on small numbers diverge between studies with young infants [14, 20, 21]. Early studies using habituation found that newborns and infants, ranging from 4 to 7 months old, discriminate between small numbers [20, 22]. However, these studies did not control for the continuous variables that covary with number. Later studies that did control for these variables found that infants could neither discriminate one from two at 6 months of age [13] nor two from three elements at 6–8 months of age [14]. However, a recent replication of the Clearfield and Mix study [14] reported a positive result for these latter numbers in 7-month-olds [21]. This study supported small number discrimination using habituation and controlling for continuous variables. Difference between this finding and that of the original Clearfield and Mix [14] paper is assumed to result from changes in data collection and analysis. Cordes and Brannon [21] used computer-generated images presented on computer monitors instead of computer-generated drawings mounted on white foam board. Furthermore, they included not only looking times of all test trial pairs in their analysis instead of only the looking times of the first test pair but also took into account the three last habituation trials instead of only the last habituation trial as in the original study [14].

As reported above, there is plenty of evidence for large number discrimination in infants using the habituation paradigm. For small numbers, however, this is not the case. One number set has, until now, been proven unsuccessful [13] while another comparison yields contrasting results [14, 21]. As a consequence, a full understanding of small number discrimination has not yet been reached. In the small number range, however, all number combinations can easily be investigated.

The current study aims to extend the previous ones by investigating the number set one versus three. This specific small number set is the only one which has not been investigated before with the habituation paradigm. Moreover, an eye tracking system is used to measure looking time more accurately than previously done in studies on number discrimination. More specifically, instead of using the reflection of the computer screen in the infant's eye [23] or considering the direction of the child's face [2, 13, 17, 24], looking time was registered on the basis of the infant's gazes to the presented stimuli using eye tracking during task administration.

2. Methods

2.1. Participants. Participants were part of a birth cohort of 3000 babies born between May 2008 and April 2009, living in different Flemish districts in Belgium. They were recruited within the scope of a longitudinal study for the Belgian government realised by the Ghent University and Catholic University of Louvain as a partnership within the support center Welfare, Public Health and Family (http://www.steunpuntwvg.be/). "Child & Family," a governmental agency with responsibility for young children and families in Flanders (http://www.kindengezin.be/), invited parents to this study. From the parents who had send back

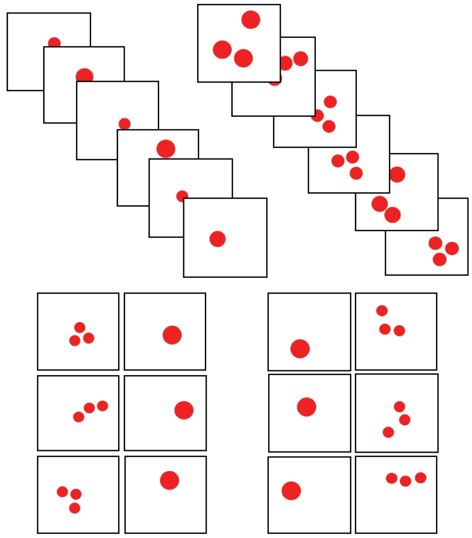

Figure 1: Example of stimuli used in the habituation and test phase (for each test trial pair).

a signed informed consent, 10% were randomly invited with a letter to participate in an additional multidisciplinary study, approved by the related academic ethical committees, of which this study is one part. Parents could fill in a new informed consent and if they consented, they were contacted by telephone. The research took place at "Child & Family" clinics. The study reported here included 16 full-term infants of which there were nine boys and seven girls. The age of the infants varied from 31 weeks (7.75 months) to 34 weeks (8.5 months), with a mean age of 32.50 weeks (8.13 months, SD = 1.10 weeks).

2.2. Stimuli. The method of this study was based on the methodology of Xu [2] and Xu and Arriage [23]. A task based on the habituation paradigm was used. Stimuli were one- and three- element arrays of red dots in a white square background displayed in the center of the eye tracker monitor. Six different habituation displays were showed in each condition. In order to maximally attract and sustain the attention of the infants, the dots were coloured red [25–27]. Furthermore, stimuli were controlled for continuous variables (item size and interitem distance at item level and the related set-parameters total item size and total occupied set area) according to the procedure of Dehaene et al. [28]. The stimuli were designed so that, besides the change in number, all parameter values presented in the test phase were also presented during habituation, thus being equally nonnovel. This could be established by randomly selecting one parameter (item or set level) from a fixed distribution regardless of the number while the related parameter varied with number in habituation stimuli. For the test stimuli, this procedure was reversed. In this experiment, total item size and total occupied area were fixed during habituation while the correlated set-level-parameters varied with number [28]. An example of stimuli used in the habituation task is shown in Figure 1.

2.3. Apparatus. Children sat on their parent's lap in front of a Tobii T60 Eye Tracker at a viewing distance of approximately 60 cm. This eye-tracking device is integrated in a 17-inch TFT monitor with a refresh rate of 60 Hz ad accuracy of 0.5 degrees allowing freedom of head movement ($4\times22\times30$ cm) [29]. Parents were instructed to remain neutral and not to elicit the child's attention during task administration. Habit X version 1.0, a software program developed for performing the habituation paradigm [30] (Cohen et al., 2004) was used for the task. One experimenter saw the infants' looking behaviour via the "live viewer" on a portable computer (connected with the eye tracker) running the software *Tobii Studio* [29]. This "live viewer" showed the eye fixations of infants on the presented stimuli during the habituation task. Looking behaviour was recorded in *Habit* by holding down a button when an infant was looking at the stimuli and releasing it when he/she looked away from the stimuli. The experimenter was blind to the experimental condition to which the child was assigned. Real looking times were coded afterwards in *Tobii Studio* from the eye tracking data by two researchers blind to the condition by creating areas of interest (with margins of 0.79 inch) around each dot per array. As such, total fixation duration at all the dots in one display could be identified. These coded looking times were then used for final analysis. Inter-rater reliability was calculated using Pearson's *r*. This was .97, indicating a good reliability between the two researchers (who both coded seven infants in a pilot study).

2.4. Procedure. At the beginning of the task, an attention grabber accompanied with sound appeared successively in the four corners and the middle of the eye-tracker screen to indicate the infant's window of looking. Only after a successful five-point calibration, the experiment began. Then, a well-known cartoon figure was shown and each following trial was introduced by a sound (to sustain infants' attention). Looking time was valid from the moment infants looked at least 0.5 s at the stimuli until they looked away for 2 s continuously (or for a maximum look of 120 s). The task consisted of a habituation and a test phase. Infants were randomly assigned to one of two habituation conditions. Half of the infants were habituated to one-dot-arrays, the others to three-dot arrays. Six different displays were presented in (repeating) random order until the infant met the habituation criterion (a 50% reduction in looking time over three consecutive trials, relative to the first three trials) or until 14 trials were completed. All infants reached the habituation criterion. Afterwards, infants were presented with six test displays containing the habituated (old) or the new number of dots in alternation (counterbalanced for order across participants).

2.5. Statistical Analysis. First, a paired *t* test comparing looking time on the first three and last three habiutation trials was conducted to confirm whether infants did habituate. The main analysiss focused on looking patterns exhibited during the test phase, which is a common practice [2, 7, 23]. Following Xu et al. [13], outlying scores (>2 SD from the mean for each condition) were excluded from analysis. In

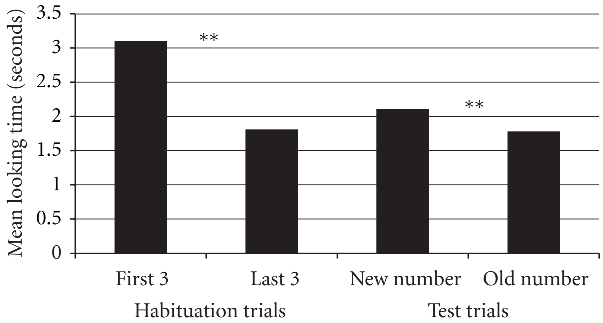

Figure 2: Mean looking times for the first three and last three habituation trials and for the new and the old number test trials across all test pairs.

accordance with Cordes and Brannon [24], these looking times were replaced with the next longest looking time for all infants in each condition. Furthermore, to avoid loss of observations with one or more missing outcomes (due to technical failure) with RM-ANOVA, a linear mixed model analysis was conducted on the looking times. This analysis tested whether looking time at the new number of dots was longer than looking time at the old number of dots in accordance with Xu et al. [2, 13, 17, 23]. The consistency of the effect across trial pair, habituation condition, and sex was also assessed. To capture the correlation between repeated measurements of a participant, an unstructured variance-covariance was assumed. In addition, the method of analysis used by Cordes and Brannon [21] was compared to that of the study by Clearfield and Mix [14].

3. Results

Figure 2 shows the mean looking time for the first three and last three habituation trials. A paired *t* test revealed a significant reduction in looking time from the first three habituation trials ($M = 3.10$, $\mathrm{SD} = 2.13$) to the last three habituation trials ($M = 1.81$, $\mathrm{SD} = 1.49$), $(15) = 4.15$, $P < .01$, Cohen's $d = 0.70$.

Figure 2 also displays the mean looking time at the old and new number (test trial type) across all three test trial pairs. The linear mixed model analysis revealed a significant larger looking time to the new ($M = 2.11$, $\mathrm{SD} = 1.25$) compared to the old number ($M = 1.78$, $\mathrm{SD} = 1.16$), $F(1, 12.59) = 9.45, P < .01$, Cohen's $d = 0.21$. No other effects of test trial pair, habituation condition or sex were found, respectively $F(2, 14.95) = 0.54$, $F(1, 13.06) = 0.35$, $F(1, 13.05) = 2.45$ with all $p > .05$. The paired *t* test comparing looking time on the last three habituation trials ($M = 1.81$, $\mathrm{SD} = 1.49$) with looking time on the new number across all test trials pairs ($M = 2.58$, $\mathrm{SD} = 1.48$), revealed no significant difference between the two measures, $t(15) = -0.87$, $P > 0.05$. The paired *t* test comparing looking time on the last habituation trial ($M = 1.50$, $\mathrm{SD} = 1.94$) with looking time on the first of each type of test trial showed a trend for an increasing looking time on the test trial with a change in number ($M = 2.58, \mathrm{SD} = 1.48$), $t(15) = -1.76$, $P < 0.10$, Cohen's $d = 0.63$.

4. Discussion

Previous research has demonstrated that infants rely on two different systems to process numbers: the object-file system is held responsible for small numbers [3, 4] and the analogue magnitude system for large numbers [1]. Up till now, evidence for the discrimination of small numbers has not been found for all small numbers using habituation [13, 14, 21]. To extent previous work, the current experiment investigated the number discrimination of the small number set one versus three. Special attention was given to the use of accurate looking time measures using eyetracking during administration of a habituation task on number discrimination. Data, furthermore, were analysed, following several approaches from habituation studies on number discrimination [2, 13, 14, 17, 21, 23].

Results, retrieved according to the analysis approach of Xu et al. [2, 13, 17, 23], revealed infants' ability to discriminate these small numbers during a habituation task. The linear mixed model analysis showed a significant small effect of number on the looking times. This successful discrimination extends previous research on small numbers. However, questions about the nature of number discrimination within this range remain. Why was number discrimination unsuccessful for one versus two [13] in contrast with the success of the one versus three set in this study? Why do findings on the two versus three set vary [14, 21]? Because of the feature of precision which is ascribed to the object-file system, it would be logical that all sets (one versus two, two versus three, and one versus three) in the small number range could be equally discriminated. Therefore, it might be possible that infants are successful in discriminating one versus two in a replication of the experiment of Xu et al. [13]. Reinvestigating the number set two versus three had this result [21] as well compared to the original study [14]. Though, referring to the introduction of this paper, the difference in this recent finding and that of Clearfield and Mix [14] is assumed to result from changes in data collection and analysis. Regarding this latter topic, data from the current study confirmed the hypothesis revealing different results retrieved from each approach [14, 21]. To summarize, results from all approaches together showed the following. Against expectations looking time at the new number did not significantly differed from looking time on the last three habituation trials according to the analysis approach of Cordes and Brannon [21]. As expected, for a succesfull number discrimination, looking time at the new number did differ significantly from looking time at the old number during the test phase following the analysis approach of Xu et al. [2, 13, 17, 23]. The former finding, based on a comparison between the looking time on the last three habituation trials and the looking time at the new number across all test trial pairs, suggests the absence of dishabituation to the new presented number. Though, analysis according to Clearfield and Mix [14] only taking into account the last habituation trial and the first test trial pair involving the new number, do actually suggests a trend of dishabituation. As such, different methods to process data do have an influence on the outcome. Referring to these results, one can question the expectation of the habituation paradigm, namely, that looking time at the new numbers in the test trials exceed the looking time at the last three habituation trials as a measure of dishabituation. This matter, however, is subject to further research and will not be discussed within the scope of the current paper. Aiming at retrieving data following Xu et al. [2, 13, 17, 23], it can be concluded that the approach of Clearfield and Mix [14] supports in some way the results retrieved from this main approach [2, 13, 17, 23].

To further discuss the success of one versus three, this result might be explained by the larger ratio of the latter number set, considering the negative outcome of the one versus two number set [13]. Although ratio-dependency is not known as a feature of the object-file system, [3, 4] raising the ratio might facilitate number discrimination as it does in large number discrimination [1, 9]. This explanation however, is in contrast with the positive evidence for the discrimination of two versus three [1] which has a smaller ratio than one versus two. Another explanation is the age of the children. The 8-month-olds were two months older than those in the study of Xu et al. [13]. It is possible that infants are able to discriminate small numbers only from a specific age on. The negative result found by Clearfield and Mix [14] may be due to the inclusion of 6-month-olds, while the result of the replication study [21] may be explained by the older age of the infants (7 months of age). Despite the fact that infants discriminate large numbers from the age of six months on [2], this might not be the case for small numbers. To our knowledge, the effect of age on small number discrimination has not been investigated yet.

Nonetheless, it should be mentioned that the method in this study did differ from previous research, which may have led to the different finding. An eye-tracking system was used to enhance accuracy of looking time measures. The online-registration of where the child was looking at enabled recording of looking behaviour on grounds of infant's gazes instead of either the reflection of a computer screen in the infant's eye [23] or just the direction of the child's face as in previous research [2, 13, 17, 24]. One can question whether an infant is looking at a random area on the computer screen or is really attentive to the presented stimuli by looking straight at it. Without devaluating the previous mentioned habituation methods, eyetracking obviously takes away any doubt in this matter. As described later on under "apparatus" in Section 2, analysis techniques of looking data such as AOI's within an area defined by the computer screen's boundaries helps to unravel the child's looking behaviour. As such, the use of eye tracking in combination with the known habituation paradigm from previous studies is more precise than the use of the paradigm on its own. This method reduces noise and, therefore, increases the possibility of revealing significant differences. This difference in methodology may also be an explanation for the smaller mean looking times registered in this study than those reported in previous studies on number discrimination [23].

Regardless of the small effect of the main result, small number discrimination of one versus three in infants is supported. However, not all previous and novel issues about the nature of small number discrimination can be solved because only one number set was used. A study examining all three small number sets in the same infants with the same precise method seems indicated to establish a better understanding of small number discrimination. This might help to reach a better insight in the ability of discriminating small numbers in infants. Within the scope of prevention, early detection of individual differences may be established by this better knowledge. Consequently, it might be possible to distinguish children at risk from typical developing children.

Conflict of Interest

There is no conflict of interests.

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