ELSEVIER
Available online at www.sciencedirect.com
SCIENCE DIRECT®
Cognitive Development xxx (2004) xxx–xxx
COGNITIVE
DEVELOPMENT

Infants’ enumeration of dynamic displays

Melissa W. Clearfield*

Department of Psychology, Whitman College, 345 Boyer Ave., Walla Walla, WA 99362, USA

Received 1 April 2003; received in revised form 1 February 2004; accepted 1 March 2004

Abstract

This study examined infants’ enumeration of puppet jumping tasks. In Experiment 1, 5–7-month-old infants were familiarized to a puppet jumping two- or three-times, and tested with both numbers of jumps. Infants looked significantly longer at the new number, replicating Wynn [Psychol. Sci. 7 (1996) 164]. To probe further the stability of infants’ ability to enumerate, Experiment 2 varied the rate of the jumps during habituation and controlled for rate across test trials. At test, infants showed no preference for either event, suggesting that rate changes can overpower infants’ responses to number. Experiment 3 explored an alternative explanation to infant’s enumeration, namely discrimination based on the amount of time the puppet spent jumping. Infants were familiarized to two or three jumps, then tested with alternating displays of either a familiar number of jumps with a novel jump time, or a novel number of jumps with the familiar jump time. Infants dishabituated to the display that changed in jump time, but not to the display that changed in number. Results suggest that infants’ looking in event sequences is based on amount of motion, not enumeration. This finding is consistent with studies finding perceptual processes behind infants’ supposed precocious numerical abilities.

Keywords: Enumeration; Dynamic display; Numerical abilities

1. Introduction

Previous research has found that very young infants react to changes in quantity (e.g., Antell & Keating, 1983; Clearfield & Mix, 2001; Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1990; Wynn, 1992; Wynn, 1996). Indeed, infants as young as 54 h old have demonstrated a response to a change in quantity (e.g., Antell & Keating, 1983). These

---

* Tel.: +1 509 522 4427.
E-mail address: clearfmw@whitman.edu (M.W. Clearfield).

0885-2014/$ – see front matter © 2004 Published by Elsevier Inc.
doi:10.1016/j.cogdev.2004.03.003

results have led researchers to conclude that infants have a sophisticated sense of discrete number.

Infants' numerical sense has been tested using three methods. The first is visual habituation to static displays (e.g., Antell & Keating, 1983; Starkey & Cooper, 1980; Starkey et al., 1990; Strauss & Curtis, 1981). In these studies, infants were repeatedly shown displays with a certain number of items (e.g., two dots). After looking time decreased to a set point, infants were shown test displays with either the familiar set size or a novel set size (e.g., two versus three dots). Across studies, infants looked longer at the display with the novel number of items, suggesting that infants were able to discriminate these displays on the basis of number.

However, it is possible to discriminate the sets based on perceptual variables associated with changes in amount, such as contour length or area. The change from the habituation displays to the test displays in all the above studies was more than simply adding or taking away one dot. There was also a change in the overall amount of black (or color) on the page, as well as a change in the amount of edge length. Indeed, when these continuous variables were pitted directly against the change in discrete number, infants attended to the change in amount (Clearfield & Mix, 1999, 2001; Feigenson, Carey, & Spelke, 2002). For example, Clearfield and Mix (1999) habituated infants to two or three squares of the same size. At test, infants saw two alternating displays—one with the familiar number but a change in overall amount (based on total contour length, area, or both), and one with a novel number but the same overall amount as the habituation trials. Importantly, the amount 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 the change in number, regardless of which aspect of amount was manipulated. This suggests that when infants dishabituated in previous studies, their responses were based on overall amount.

The second method used to explore infants' numerical abilities is based on the possible versus impossible event paradigm (Simon, Hespos, & Rochat, 1995; Wynn, 1992). In these experiments, infants were shown simple addition and subtraction problems using dolls. Five-month-old infants watched as one puppet was placed behind a screen and then a second puppet was placed behind the same screen, after which the screen was lowered to reveal either one or two puppets. Infants looked longer at the incorrect solution, leading Wynn to conclude that infants can add and subtract small numbers. However, Feigenson et al. (2002) 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. In one experiment, 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 looked longer toward the unexpected change in volume, not the change in number. Thus, as in Clearfield and Mix's (1999) habituation study, infants appeared to use overall amount instead of number in calculation tasks. Moreover, recent studies indicate that infants' looking patterns on these addition tasks may be a result of familiarization effects (Cohen & Marks, 2002; Clearfield & Westfahl, in press).

Thus, using two very different methodologies to assess infants' numerical understanding, infants' behavior in both was based on perceptual variables. However, the third method used to assess infants' numerical sense does not involve changes in quantity like those described above. Instead, infants are asked to enumerate event sequences. In the first study to explore this, Wynn (1996) habituated infants to a puppet jumping either two- or three-times with a pause between jumps. The rate and duration of the jump sequences were varied so that infants couldn't base discriminations on those variables. At test, infants saw two alternating sequences of the puppet jumping two- and three-times. She found that infants looked significantly longer at the novel number of jumps, whether there was a pause between jumps or not. This finding was extended to include different combinations of movements, such as jumps and falls (Sharon & Wynn, 1998).

This appears to be strong evidence for infants' ability to enumerate the number of puppet jumps. Thus, it is critical that this result be replicated, which was the goal of Experiment 1. Further, given that this finding is one of the few remaining findings pointing to early mathematical knowledge, it is important that the limits of the knowledge be tested. To that end, the goal of Experiment 2 was to probe the robustness of infants' ability to enumerate by varying rate across the habituation trials (within the same number of jumps). If infants' ability to enumerate is robust, they should be able to extract number from the jumping patterns even across rate changes.

Experiment 3 tests an alternative hypothesis to infants' mathematical knowledge as an explanation for Wynn's (1996) results. One critical difference between a puppet jumping two-times and puppet jumping three-times is the amount of time the puppet spends in motion. In Wynn's (1996) experiments, the rate of the puppet jumping was the same; each puppet jump lasted 1 s:1/2 s jumping up, and 1/2 s coming down. After an infant was habituated to two jumps (with the puppet spending two full seconds in motion), the infants then saw either two jumps with a new rate or duration but still the same 2 s of motion, or three jumps, where the puppet now spent 3 s in motion. Thus, infants could have based their discriminations on the amount of time the puppet was in motion.

Indeed, motion is well-known to be highly salient to infants. Even newborn infants under 15 h old prefer to look at a moving stimulus compared to an identical stationary stimulus (McKenzie & Day, 1976; Slater, Morison, Town, & Rose, 1985 for 2–4-month-old infants). Infants can also discriminate changes in patterns of motion (e.g., Bogartz, Shinskey, & Schilling, 2000; Cashon & Cohen, 2000). One classic example is based on Baillargeon's (1987) studies of 8-month-old infants' perception of object permanence. In this paradigm, infants are familiarized to a screen rotating either 180 or 112° and then shown alternating test trials where the screen rotates to both angles, either with or without a box placed in the path of the screen's rotation. Infants looked longer at perceptually novel displays, including changes in the angle of rotation of the screen. Leaving aside the implications of the results for the debate on object permanence, the critical point here is that infants were able to distinguish angles of rotation, lending further support to the salience of motion.

Beyond preferences for motion and the ability to discriminate slight differences in patterns of motion, infants as young as 3 months of age have been shown to remember specific patterns of motion (Bahrick & Pickens, 1995). In this study, after infants were familiarized to an object moving in either a familiar or novel motion pattern, they were assessed for visual preferences for the patterns of motion at varying time intervals. Infants demonstrated significant visual preferences for the familiar motion after 1 and 3 months. This suggests that not only do infants attend to patterns of motion, but that motion is such a salient characteristic that infants retain it in long-term memory. Indeed, research on infants' visual system has identified specific cells in the visual system that respond to movement (e.g., Dobkins & Teller, 1996; Hamer & Norcia, 1994). Interestingly, these cells undergo very little development over the course of the first year of life. Indeed, the pattern of results from 3-month-old infants with respect to how quickly the cells responded to motion and how much change was necessary to evoke a response did not differ from the patterns of adults (Dobkins & Teller, 1996). Thus, these motion detectors are highly advanced, even in very young infants.

The purpose of the present study was to probe the limits of infants' enumeration, and to test whether infants base their discriminations of dynamic jumping events on the number of jumps or the amount of time spent jumping. This is a critical issue, because in theory, all the different methods should produce similar results if infants can indeed enumerate. That is, infants should show signs of enumeration whether in a discrimination task, addition task, or enumeration task. The fact that two of the methods have already converged on an alternative perceptual explanation raises questions about the remaining methodology. Thus, it is critical to replicate and extend the few findings that demonstrate enumeration in dynamic events. Experiment 1 was a simple replication of Wynn's (1996) original results, which was required in order to assess the reliability of the finding, as well as the procedure. In Experiment 2, rate was varied across the habituation trials (within the same number of jumps) as a further test of infants' ability to enumerate. In Experiment 3, the amount of time the puppet spent in motion was pitted against number of jumps to determine whether amount of motion was the underlying basis of infants' discrimination in the enumeration task.

2. Experiment 1

2.1. Method

2.1.1. Participants

Sixteen 5–7-month-old infants (8 males, 8 females; $M = 6.39$ months, range: 5.5–7.6 months) participated in this study. There was no attrition. Infants were recruited through local published birth announcements, and then contacted by mail. All participants received a small gift for participating.

2.1.2. Design

The design of this experiment was identical to the design of Wynn (1996). Infants were habituated to either two or three puppet jumps. Then, infants were presented with four test trials in which the puppet alternately jumped two- and three-times. The order of the test displays was counterbalanced across infants. Half the infants within each habituation and order group saw test trials controlled for tempo, and the other half saw test trials controlled for overall duration. Fig. 1 shows the breakdown of each condition by number of jumps, timing controls, and overall tempo and duration of the jump sequence.

2.1.3. Apparatus

Infants sat in an infant seat located 60 cm from the display in a small quiet room surrounded by black curtains. Infants faced a wooden stage (61 cm × 36 cm), lit by a fluorescent tube light on the top of the stage. A curtain was attached to the top of the stage to make the

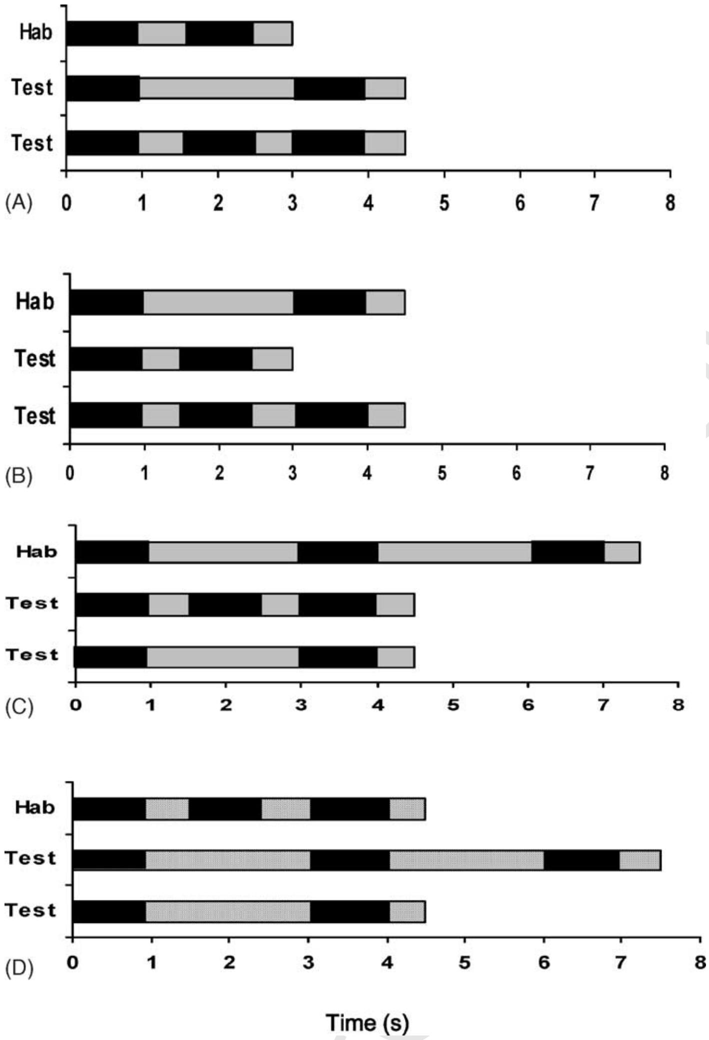

Fig. 1. Structure of jump sequences in Experiment 1 (replication of Wynn, 1996). Black bars depict time spent jumping, and the gray depicts the time when the puppet was stationary. (A) and (B) show the two possible sequences for habituating to two jumps; (C) and (D) show the sequences for three jumps. Conditions (A) and (C) control for duration (note that both test sequences differ in overall duration from the habituation sequence), while conditions (B) and (D) control for rate (note that both test sequences have the same inter-jump-interval). Note too that all jumps lasted 1 s (1/2 s up, 1/2 s down).

stage visible or hidden to the infant. One experimenter performed the puppet show 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. The experimenter recording looking time was unable to tell what displays were being presented. A visual metronome was used to keep time (a light flashed the timing), and soft classical music played in the background.

2.1.4. Procedure

Infants were seated in their parent's lap facing the display. Parents were instructed not to speak to or interact with their infants during the experiment. Prior to the experiment, infants were given the puppet to play with for a minute. Infants were then shown the stage by a black-gloved hand patting the floor and walls of the stage. On habituation trials, the curtain was raised to reveal the stationary puppet. After a 1 s pause, the puppet began the jumping sequence, measuring time and tempo with a metronome. Infants' looking time was recorded beginning 1/2 s after the puppet stopped jumping, and was thus recorded while the puppet was still. Looking time commenced as soon as the infant first fixated on the display once it stopped jumping, identical to Wynn (1996). Each trial consisted of one jumping sequence, and lasted for 10 s. The curtain was then lowered for 11/2 s, and then was raised again to begin the next trial. Infants saw one instantiation of the jumping event during each habituation trial. Infants were presented with a maximum of 16 habituation trials. 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. After infants were habituated, they received a 40 s break, during which time they were faced away from the display and allowed to interact with a parent, following Wynn (1996). Infants were then shown the four alternating test trials.

2.1.5. Coding and reliability

In order to test the reliability of the on-line coder, a second coder who was blind to the experimental conditions measured looking time from 20% of the videotaped sessions. Inter-rater agreement was high ($r^2 = 0.92$), so the on-line recordings were used in all subsequent analyses.

2.2. Results and discussion

A summary of the average looking times for the test trials is presented in Fig. 2. As shown in the figure, infants looked longer at the new number ($M = 3.177$ s) than the familiar number ($M = 1.193$ s). A mixed repeated measures analysis of variance was conducted, with number of jumps during habituation, sex, and control condition (tempo or duration) as between-subjects factors and trial kind (familiar or new number of jumps) as the within-subjects factor. There was a main effect for trial kind type, with longer looking times for the new number than the familiar number ($F(3,12) = 5.875$, $P < 0.05$). There were no other effects or interactions.

In order to determine whether infants dishabituated to either of the test displays, paired *t*-tests were conducted between the last habituation trial and the first of each type of test trial. Both *t*-tests revealed a significant difference in looking time, with infants looking longer at the familiar number ($t(15) = 2.64, P < 0.05$) compared to the last habituation trial, as well as the novel number ($t(15) = 4.96, P < 0.05$). The significance of this will be discussed below.

Thus, infants detected a change between the habituation and test displays, and looked longer at the display that changed in number, rather than tempo or duration. These results

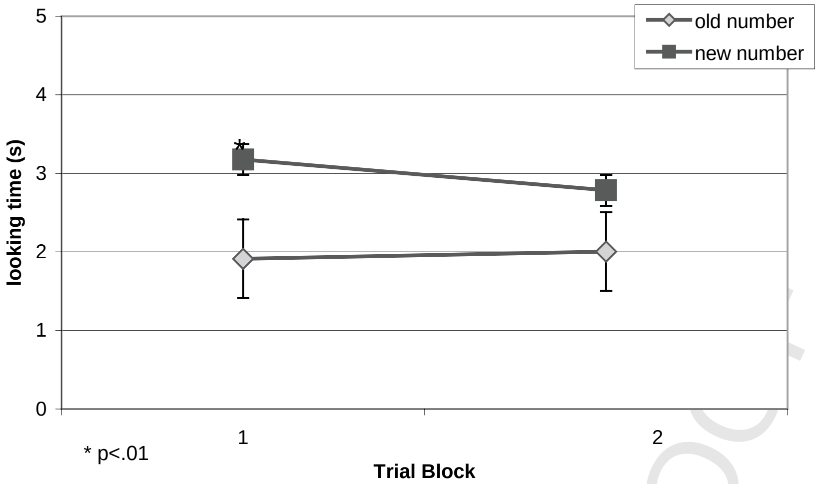

Fig. 2. Mean looking times on the test trials for Experiment 1.

replicate those reported by Wynn (1996), thus indicating the reliability of the original finding. Importantly, this result also indicates that the procedure used in the present study is similar enough, if not identical, to that used by Wynn (1996). Thus, any further manipulations should be comparable.

3. Experiment 2

Wynn's interpretation of these results is that infants can enumerate event sequences. According to Wynn (1996), they are able to attend to number even across changes in rate or duration. Thus, if her interpretation is correct, changes in rate during the habituation trials should not interfere with infants' ability to discriminate based on number during the test trials. That is, if infants are truly able to extract number from the puppet jumping displays, varying the rate of the jumps during familiarization should not make a difference. Experiment 2 tested this hypothesis by varying the rate of the jumps, but not the number, during familiarization. At test, infants saw both the familiar and novel number of jumps, both with a new rate from the familiarization trials, but the same as each other. If infants' enumeration is based on the change in number, regardless of the change in rate, then infants should look longer at the novel number in the test trials.

3.1. Method

3.1.1. Participants

An additional 24 5–7-month-old infants (12 males, 12 females, $M = 5.56$ months, range: 4.97–6.57 months) participated. Data from an additional five infants were not included due to a change in procedure. Infants were recruited through local birth announcements and contacted by mail. All infants received a small gift for participating.

3.1.2. Design

Infants were randomly assigned to a familiarization condition (two jumps or three jumps; 12 infants in each, counterbalanced for sex). Within each condition, infants were assigned to 1 of 2 random orders for the rate of the habituation trials. Infants were habituated to the puppet jumping in 1 s regular beats (1/2 s up, 1/2 s down) with no pause between jumps, 1/2 s between jumps, and 11/2 s between jumps (see Fig. 3). These three difference rates were presented in random order throughout the familiarization trials. Then, infants were presented with four test trials in which the puppet alternately jumped two- and three-times. The test jumps were the same length, but both had 1 s between jumps. Thus, both test trials had a new rate from the habituation trials, but the same as each other. The order of the test displays was counterbalanced across infants.

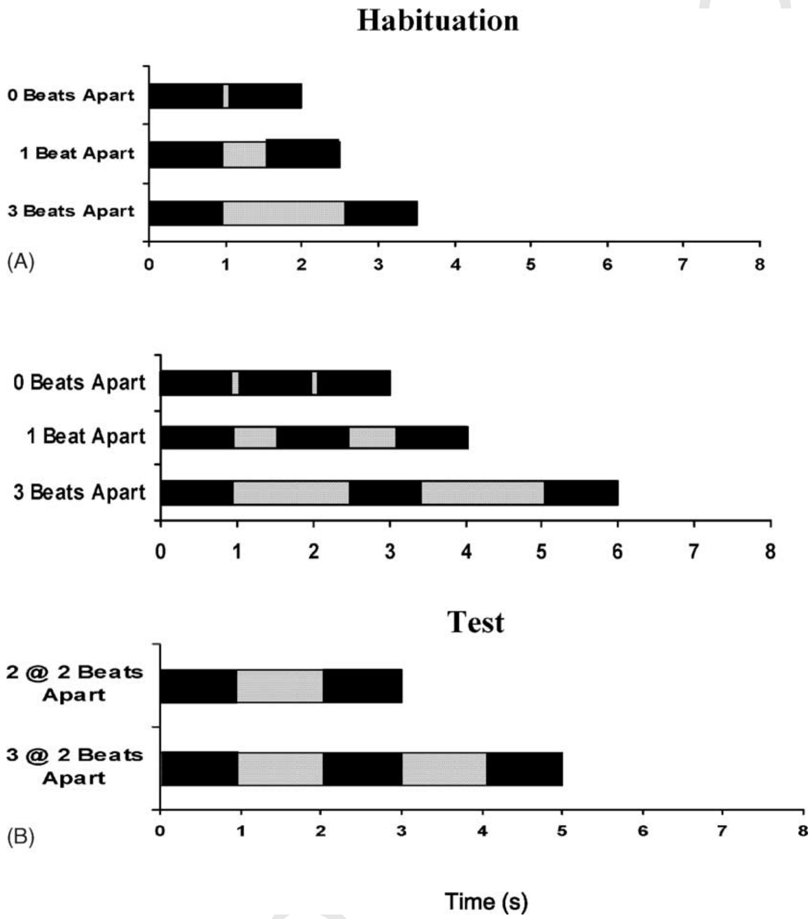

Fig. 3. Structure of jump sequences in Experiment 2. Black bars represent jumps, and the gray represents the time when the puppet was stationary. (A) depicts the possible jump sequences for two jumps, while (B) shows the sequences for three jumps. Note that infants in each condition saw all three sequences, presented in one of two random orders. All infants saw the same alternating test trials, counterbalanced for order of presentation.

3.1.3. Apparatus and procedure

The apparatus was the same as Experiment 1. The only difference in procedure was that infants were shown 16 familiarization trials before the test trials. Familiarization was used in this paradigm as opposed to habituation because habituation is difficult when varying perceptual variables within dynamic displays (e.g., Feigenson et al., 2002).

3.1.4. Coding and reliability

Again, a second coder blind to the experimental conditions measured looking time from 20% of the videotaped sessions to test the reliability of the on-line coder. Inter-rater agreement was high ($r^2 = 0.93$), so the on-line recordings were used in all subsequent analyses.

3.2. Results and discussion

On the test trials, infants showed no preference for either event (1.86 s to the novel number compared to 2.64 s to the familiar number), as revealed by a 2(habituation: 2 or 3 jumps) × 2(control condition: tempo or duration) × 2(trial kind: familiar or new number of jumps) ANOVA ($F(2,20) = 0.452$, n.s.) (see Fig. 4). According to Fig. 4, infants appear to look longer at the familiar number, although it did not reach statistical significance. However, the individual data show that eleven of the 24 infants show this pattern, while the other 13 look slightly longer at the novel number. Moreover, the average amount of difference between the two test trials was less than 1 s. These data suggest that there is really is no preference, and this result is not due to a lack of power or not enough subjects.

This result calls into question Wynn's (1996) assertion that infants enumerate. Indeed, in this experiment, they did not. Varying the rate over the course of the familiarization trials did not lead infants to respond on the basis of number. Rather, this experiment demonstrated that even after 16 familiarization trials to a particular number, infants still did not respond to a change in number. Instead, changing the rate for the test trials resulted in infants' looking

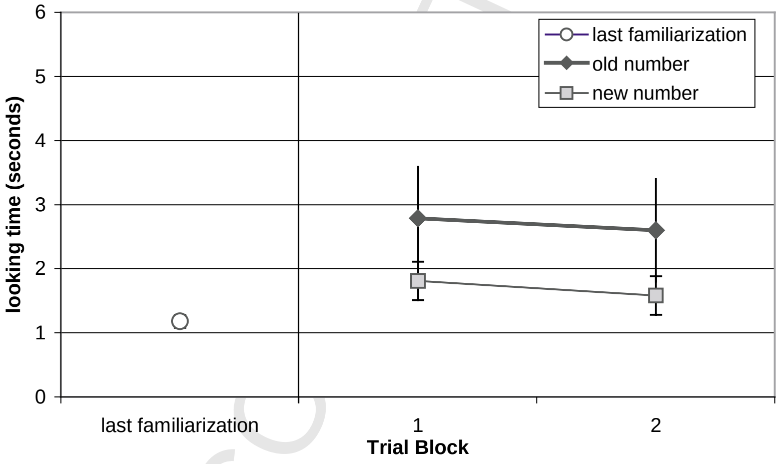

Fig. 4. Mean looking times on the test trials for Experiment 2.

equally at both the novel and familiar number. This is critical because the rate of the jump sequence was the same for both test trials. The only factor that differed between the two test trials was number, and infants still did not attend to it.

Interestingly, paired *t*-tests revealed that infants looked significantly longer at both the familiar number ($t(23) = 2.205$, $P < 0.05$) and the novel number ($t(23) = 2.483$, $P < 0.05$) compared to the last familiarization trial. This suggests that the rate of the jumping was the critical factor, since that changed for both test trials. If infants had encoded number, they should have looked significantly longer at the novel number only. Moreover, if the display was so complicated that the infants hadn't finished encoding it, then they should have looked significantly longer at the familiar number (Schilling, 2000). And if some infants were finished encoding, and others were not, then there should not have been any difference at all compared to the last familiarization trial. The fact that there was a significant increase based on a change in the rate indicates that rate is a highly salient factor.

Indeed, most of the infants (18 of 24) in this experiment did not reach the criterion for habituation. That is, looking time over the course of the familiarization trials did decrease, but not to the standard 50% of the first three trials. This is a highly striking finding, in light of the claims made about infants' enumeration abilities. If infants are really able to extract two from a puppet jumping two-times, they should be able to do so even when the pauses in between jumps change slightly. The fact that they do not even habituate to that, nor look longer at a change in number after 16 exposures to a different number, suggests that the rate is itself salient.

This is reinforced by the fact that in Experiment 1, infants dishabituated to both test displays. Looking at the details of the displays themselves reveals why this finding is important. For all conditions, the test trial where number remained the same was necessarily a change in rate. And recall that infants dishabituated to both test displays in Experiment 1, even though they looked longer at the display that changed in number. Hence, rate itself must be one of the features to which infants attend.

But of course, Wynn (1996) controlled for rate in a way that rules it out as the sole explanation for all of the findings, although it may explain some of the results. So what the present experiment shows is that: (1) rate is a salient factor in infants' discrimination of dynamic events, and (2) infants' enumeration appears to be fragile and easily disrupted by changes in rate. The question that remains is: on what basis or bases did infants discriminate in the test trials which differed in number but not in rate? The results from Experiment 2 suggest that the answer is not number. An alternative, namely the amount of time spent in motion, is tested in Experiment 3.

4. Experiment 3

As a first step in determining another factor that might underlie infants' looking behavior in this task, a close examination of the jumping sequence is required. Looking closely at Fig. 1, it appears that there is another variable that is correlated with changes in number, i.e., amount of motion. The length of the puppet jumps was identical across all trials (1 s total). Therefore, adding an extra jump increases the time that the puppet is in motion. Conversely,

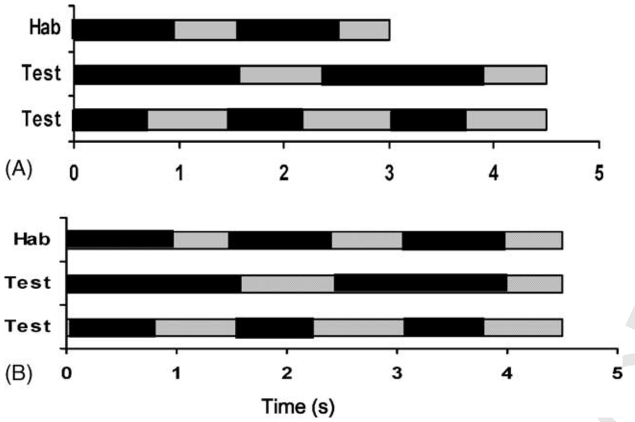

Fig. 5. Structure of jump sequences in Experiment 3. Black bars depict jumps, and the gray represents the time when the puppet was stationary. Note that all the jumps during habituation lasted 1 s (1/2 s up, 1/2 s down) with a 1/2 s pause, just as in Experiment 1 and Wynn (1996). During the test trials, infants were presented with two jumps where each one lasted 1 1/2 s (3/4 s up, 3/4 s down) and three jumps where each one lasted 2/3 s (1/3 s up, 1/3 s down). Note that the order of the test trials was counterbalanced across infants.

eliminating a jump decreases the amount of time the puppet is in motion. This is critical because the rest of the display is static and boring. When the puppet is not moving, it is sitting on a black stage, in a room surrounded by black curtains, with nothing else to look at except for the motionless puppet. The only interesting event in the testing session is the jumping motion of the puppet. And as described above, it is well-known that motion tends to capture infants' attention.

Returning to Wynn's (1996) study and Experiment 1 here, it is possible that increasing or decreasing the amount of time that the puppet spends jumping is enough to capture infants' attention. Moreover, it is possible that it is this increase, and not the increase in number, that resulted in infants' discriminations. Experiment 3 tested this possibility by habituating infants to two or three puppet jumps, and then presenting two alternating test displays. In one display, the number of jumps was familiar, but the amount of time the puppet was in motion varied, such that it equaled the amount of motion there would have been had we added or subtracted a jump (see Fig. 5). In the other test display, the number of jumps changed but the total amount of jumping time was exactly the same as it was in the habituation trials. If infants attend to amount of time spent jumping, they should dishabituate to the familiar number/different amount of jumping display. If they attend to number, they should dishabituate to the different number/familiar amount of jumping display.

4.1. Method

4.1.1. Subjects

Subjects were 16 healthy, full-term babies (8 females, 8 males) 6–8 months of age (mean: 6.9 months, range: 6 – 7.8). One additional infant was excluded due to fussiness. Infants were recruited through local birth announcements and were given a small gift for participating.

4.1.2. Design

Half the infants were habituated to two 1 s jumps and half were habituated to three 1 s jumps. For the habituation trials, all jumps were 1 s long, identical to Wynn (1996) and Experiment 1. Following the habituation trials, infants were presented with six test trials that alternated between number and amount of jumping motion. Half the infants in each group saw the display differing in number first, and half saw the display differing in jump length first. Equal numbers of boys and girls participated in each condition.

For the test trials, the jumping length was determined by the amount of jump time there would have been had we added or subtracted a jump. Thus, the test trials alternated between two $11/2$ s jumps (for a total of 3 s, just as if we had added a 3rd 1 s jump; note that is also identical to the 3 s of jump time that infants who were habituated to three jumps saw) and three $2/3$ s jumps (for a total of 2 s). The same alternating test trials were used for both conditions (i.e., habituated to two or three jumps). For infants habituated to three 1 s jumps, the test trials alternated between two $11/2$ s jumps (for a total of 3 s, so different number, same time spent jumping) and three jumps lasting 2/3rds of a second each (same number of jumps, only 2 s total jumping time). The change in duration for this kind of test trial was controlled by increasing the length of the pauses in between jumps (see Fig. 5). Thus, duration of the event display was controlled across habituation and test trials, and rate was kept constant. The speed of the jumps was controlled, so that the height varied slightly.

4.1.3. Apparatus and procedure

The apparatus and procedure were the same as Experiment 1.

4.1.4. Coding and reliability

In order to test the reliability of the on-line coder, a second coder blind to the experimental conditions measured looking time from 20% of the videotaped sessions. Inter-rater agreement was high ($r^2 = 0.92$), so the on-line recordings were used in all subsequent analyses.

4.2. Results and discussion

A summary of the average looking times on the test trials is presented in Fig. 6. As shown in the figure, infants looked longer at the change in jump time with the familiar number of jumps ($M = 2.56$ s) compared to the new number with the familiar amount of jump time ($M = 1.07$ s). A mixed repeated measures analysis of variance was conducted, with number of jumps during habituation, which test trial the infant saw first, and trial pair (infants were presented with six alternating test trials; trial pair 1 consisted of the first presentation of the familiar number and the novel number) as between-subjects factors and trial kind (familiar or novel number of jumps) as the within-subjects factor. There was a main effect for trial kind, with longer looking times for the new jump time/familiar number than the familiar jump time/novel number ($F(2,23) = 28.179$, $P < 0.0001$). There were no other effects or interactions.

Thus, infants based their discrimination on changes in jump time, not changes in number. When number remained constant and only the amount of time the puppet spent in motion changed, infants looked significantly longer, compared to when the jump time stayed

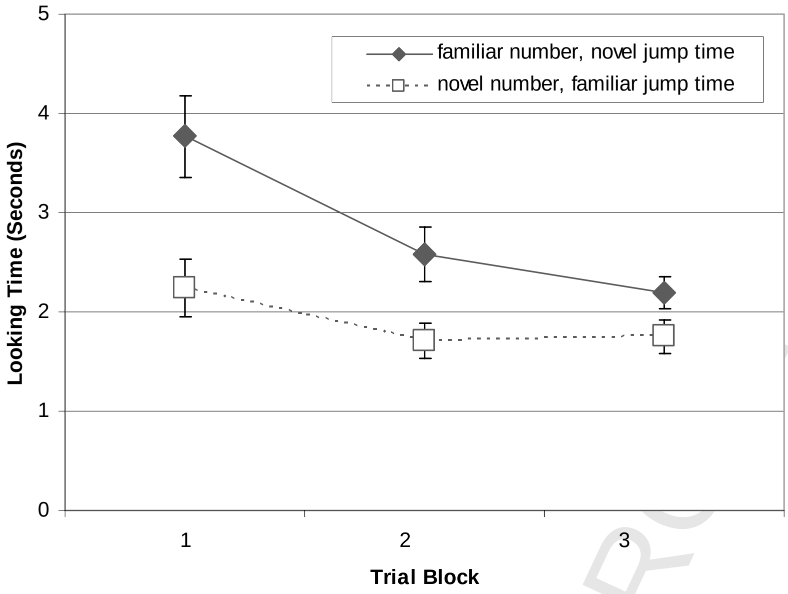

Fig. 6. Mean looking times on the test trials for Experiment 3.

the same and number changed. This is remarkable, given that the change in jump time seems minor. This suggests that amount of motion is a more salient variable to infants than number.

5. General discussion

The present studies explored whether an experiment that had been taken as evidence of enumeration in very young infants might instead reflect sensitivity to a perceptual dimension of the display. Experiment 1 replicated the original finding that infants look longer at a novel number of jumps when rate and duration are controlled. In an attempt to probe the stability of infants' enumeration, infants in Experiment 2 were presented with familiarization displays that varied in rate within the same number of jumps. However, there was no evidence that infants responded to a change in number of jumps, but they did respond to the change in the rate. In Experiment 3, amount of time the puppet spent moving was pitted directly against number. Here, infants looked significantly longer at the change in jump time, not the change in number.

The attention to rate evidenced by Experiment 2 is consistent with numerous studies demonstrating that infants, and even newborns, are highly sensitive to rhythm or rate (e.g., Dermany, McKenzie, & Vurpillot, 1977; Gibson, 1969). The present results are also consistent with the proposal that people and non-human animals can represent quantities in terms of temporal pattern matching or "rhythmic subitizing" (Davis & Perusse, 1988; vonGlasersfeld, 1982). At the very least, this finding raises questions about the robustness of infants' abilities to enumerate. If slight changes to the rate during familiarization are enough to override sensitivity to number, this suggests that that sensitivity may not be very strong.

As noted above, Wynn (1996) did control for some changes in rate, so this finding does not explain away the original result. However, in every condition in the original experiment (and Experiment 1 here), the test display with the same number of jumps was always a change in rate, in order to control for duration. This might explain why infants dishabituated to both test displays. The display with the same number of jumps changed in rate, while the display with a novel number of jumps changed in amount of time spent jumping.

Indeed, the results from Experiment 3 suggest that the amount of jump time is a highly salient cue, salient enough to override number, and possibly changes in rate. The fact that infants did not respond to the change in number in Experiment 3 is striking. If infants are really encoding “2” things or “3” things, as has been argued previously (e.g., Wynn, 1996), they should generalize to the same number of things even when the “things” differ slightly. The difference in the jump times was small: 1 s per jump in habituation compared to 2/3 of a second per jump, or 11/2 s per jump. And yet, infants were highly sensitive to these slight changes to it, compared to a change in the number of jumps. The findings from all the experiments together suggest a hierarchy of discriminative cues, with amount of motion being more salient than rate. This does not mean that infant can’t, under any circumstances, enumerate. However, the present data do suggest that perceptual cues, such as rate and motion, are more salient to infants than number, and further, that these cues may explain earlier findings previously attributed to enumeration (i.e., Wynn, 1996).

This finding adds to a growing literature reporting alternative explanations for infants’ supposed precocious numerical abilities. It is now clear that early research habituating infants to static numerical visual displays did not demonstrate sensitivity to number, as previously thought (e.g., Antell & Keating, 1983), but rather, sensitivity to continuous amount (e.g., Clearfield & Mix, 1999, 2001). Similarly, perceptual effects such as continuous amount and familiarization have also been found to underlie infants’ responses in calculation tasks (Clearfield & Westfahl, in press; Feigenson et al., 2002).

Moreover, studies looking for evidence of enumeration of events using intermodal matching tasks have produced mixed results at best. Starkey et al. (1990) presented infants with visual displays of two or three objects while they heard either two or three drumbeats. Infants looked longer toward the display that matched the number of beats, leading Starkey et al. (1990) to conclude that infants cannot only count the number of dots and the number of drumbeats, but relate those to each other on the basis of number. However, later studies have challenged this conclusion. Attempts to replicate Starkey et al.’s finding have failed; two replication attempts reported that infants actually looked longer at the display that did not match the number of drum beats (Mix, Levine, & Huttenlocher, 1997; Moore, Benenson, Reznick, Peterson, & Kagan, 1987). Moreover, Mix et al. (1997) found that infants do not look longer at the matching display when the rate and duration of the drumbeat sequences is varied randomly. Thus, infants in the previous experiments may not have been matching on the basis of number.

Taken as a whole, these studies call on researchers to explore fully the contributions of perceptual variables in infant looking data. This is especially critical in studies where the results from looking tasks are used to support arguments for higher-level abstract thought in infants. This argument is based on the premise that researchers can define the essence of some core knowledge structure, eliminate all the perceptual or task variables that could limit use of that knowledge, and determine if infants truly possess the core knowledge. However, there is now mounting evidence, at least with respect to infants' sensitivity to number, that this simply does not work. The perceptual variables can never be stripped away because the tasks used are necessarily perceptual tasks. Researchers have generally assumed that looking does not have performance limitations or preferences. However, perceptual preferences exist based on the physical structure of the visual system (e.g., Hubel & Weisel, 1962). The present results highlight the importance of considering looking preferences as a component of experimental tasks, not just as the outcome measure.

Uncited references

Canfield and Smith (1996), Roder, Bushnell, and Sasseville (2000) and Thelen and Smith (1994).

Acknowledgments

I thank Shannon Westfahl, Daniel Overgaag, Molly Mullen, Naree Nelson, and Elizabeth Karas for help with data collection. I gratefully acknowledge all the parents and infants who participated in this research. I also thank the anonymous reviewers for their helpful suggestions on the manuscript. Portions of these data were presented at the April 2003 meeting of the Society for Research in Child Development in Tampa, FL.

References

Antell, S., & Keating, D. P. (1983). Perception of numerical invariance in neonates. *Child Development*, *54*, 695–701.

Bahrick, L. E., & Pickens, J. N. (1995). Infant memory for object motion across a period of three months: Implications for a four-phase attention function. *Journal of Experimental Child Psychology*, *59*(3), 343–371.

Baillargeon, R. (1987). Object permanence in 31/2- and 41/2-month-old infants. *Developmental Psychology*, *23*(5), 655–664.

Bogartz, R. S., Shinskey, J. L., & Schilling, T. H. (2000). Object permanence in five-and-a-half-month-old infants? *Infancy*, *1*(4), 403–428.

Canfield, R. L., & Smith, E. G. (1996). Number-based expectations and sequential enumeration by 5-month-old infants. *Developmental Psychology*, *32*, 269–279.

Cashon, C. H., & Cohen, L. B. (2000). Eight-month-old infants' perception of possible and impossible events. *Infancy*, *1*(4), 429–446.

Clearfield, M. W., & Mix, K. S. (1999). Number versus contour length in infants' discrimination of small visual sets. *Psychological Science*, *10*, 408–411.

Clearfield, M. W., & Mix, K. S. (2001). Amount versus number: Infants' use of area and contour length to discriminate small sets. *Journal of Cognition and Development*, *2*(3), 243–260.

Clearfield, M. W., & Westfahl, S. M. -C. (in press). Familiarization in infants' perception of addition problems. *Journal of Cognition and Development*. in press.

Cohen, L. B., & Marks, K. S. (2002). How infants process addition and subtraction events. *Developmental Science*, *5*(2), 186–212.

Davis, H., & Perusse, R. (1988). Numerical competence in animals: Definitional issues, current evidence, and a new research agenda. *Behavioral and Brain Sciences*, *11*, 561–615.

Dermany, L., McKenzie, B., & Vurpillot, E. (1977, April). Rhythm perception in early infancy. *Nature*, *266*, 718–719.

Dobkins, K. R., & Teller, D. Y. (1996). Infant contrast detectors are selective for direction of motion. *Vision Research*, *36*(2), 281–294.

Feigenson, L., Carey, S., & Spelke, E. (2002). Infants' discrimination of number vs. continuous extent. *Cognitive Psychology*, *44*, 33–66.

Gibson, E. J. (1969). *Principles of perceptual learning and development*. New York: Appleton-Century-Crofts.

Hamer, R. D., & Norcia, A. M. (1994). The development of motion sensitivity during the first year of life. *Vision Research*, *34*(18), 2387–2402.

Hubel, D. H., & Weisel, T. N. (1962). Receptive fields, binocular interaction, and functional architecture in the cats' visual cortex. *Journal of Physiology (London)*, *160*, 106–154.

McKenzie, B. E., & Day, R. H. (1976). Infants' attention to stationary and moving objects at different differences. *Australian Journal of Psychology*, *28*(1), 45–51.

Mix, K. S., Levine, S. C., & Huttenlocher, J. (1997). Numerical abstraction in infants: Another look. *Developmental Psychology*, *33*, 423–428.

Moore, D., Benenson, J., Reznick, J. S., Peterson, M., & Kagan, J. (1987). Effect of auditory numerical information on infants' looking behavior: Contradictory evidence. *Developmental Psychology*, *23*, 665–670.

Roder, B. J., Bushnell, E. W., & Sasseville, A. M. (2000). Infants' preferences for familiarity and novelty during the course of visual processing. *Infancy*, *1*, 491–507.

Sharon, T., & Wynn, K. (1998). Individuation of actions from continuous motion. *Psychological Science*, *9*, 357–362.

Simon, T., Hespos, S., & Rochat, P. (1995). Do infants understand simple arithmetic? A replication of Wynn (1992). *Cognitive Development*, *10*, 253–269.

Slater, A., Morison, V., Town, C., & Rose, D. (1985). Movement perception and identity constancy in the newborn baby. *British Journal of Developmental Psychology*, *3*(3), 211–220.

Starkey, P., & Cooper, R. G., Jr. (1980, November). Perception of numbers by human infants. *Science*, *210*, 1033–1035.

Starkey, P., Spelke, E. S., & Gelman, R. (1990). Numerical abstraction by human infants. *Cognition*, *36*, 97–128.

Strauss, M. S., & Curtis, L. E. (1981). Infant perception of numerosity. *Child Development*, *52*, 1146–1152.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge: MIT Press.

vonGlasersfeld, E. (1982). Subitizing: The role of figural patterns in the development of numerical concepts. *Archives de Psychologie*, *50*, 191–218.

Wynn, K. (1992, August). Addition and subtraction by human infants. *Nature*, *358*, 749–750.

Wynn, K. (1996). Infants' individuation and enumeration of actions. *Psychological Science*, *7*, 164–169.