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Chapter 5

A DYNAMIC ACCOUNT OF INFANT LOOKING BEHAVIOR IN SMALL AND LARGE NUMBER TASKS

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ABSTRACT

It is well-known that infants react to changes in quantity. For many years, researchers assumed that infants' performance in small number tasks was due to precocious number sense. However, new evidence has demonstrated that infants' sensitivity to continuous variables, rather than number, underlies infants' behavior in these tasks. More recently, numerous studies have tested infants on similar tasks with large numbers. Results, again, suggest that infants demonstrate precocious numerical understanding, leading many to argue that infants have a separate, numerically-based system for discriminating and counting large numbers. However, the controls for amount in these tasks differ dramatically from those in the small number tasks, specifically in ways that maximize changes in perceptual variables that are known to impact looking behavior. Here, I ask whether controlling for those perceptual variables affects infants' looking on large number tasks.

I test this possibility by pitting number against a salient perceptual variable (edge length) with the proper controls in a large number task. Thirty-two 5-7-month-old infants were tested in two experiments. Experiment 1 explored infants' discrimination of 8 from 16, and Experiment 2 focused on infants' discrimination of 8 from 12. Results from both experiments showed that infants looked significantly longer at the change in edge length, and did not dishabituate to the change in number.

These results demonstrate that infants' looking patterns in large number displays are based on changes in perceptual variables, not changes in number. In the final sections, I offer a theoretical explanation for infants' behavior on the wide range of number tasks by drawing on the dynamic field model of infant habituation. Specifically, I propose that

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effects that have been attributed to infants' conceptual knowledge, of either number or amount, may be explained by the dynamics of the habituation process and visual attention.

INTRODUCTION

The goal of cognitive science is to understand the nature of cognition across all levels, including molecular, cellular, and behavioral. Part of that understanding involves exploring where that cognition comes from, how knowledge is acquired, and how it changes over time. These questions regarding the origins of knowledge lead developmental psychologists back to the age-old nature-nurture debate. What kinds of knowledge about the world do humans have before they are exposed to, or taught about, the objects of that knowledge? What kinds of knowledge emerge only after experience in the world?

One question that has interested developmental psychologists over the last three decades is what very young infants know about number. Number is a particularly interesting arena for this debate, because on the one hand, some animals show an impressive understanding of quantity, especially with respect to food caches and predators. On the other hand, number is an abstract concept that is effortfully taught to children starting in the pre-school years and continuing through high school and college.

To explore the extent of infants' numerical knowledge, developmental psychologists have sought to determine the earliest ages at which infants can demonstrate some understanding of number. Researchers have devised elegant and sometimes complex methods that enable very young infants to show some sensitivity to different aspects of number. Infants' success at these tasks is then taken as evidence for core knowledge that is specific to number (e.g., Feigenson, Dehaene & Spelke, 2004; Wynn, 1995).

The goal of this chapter is to review the work on infant number competencies, to assess the evidence and methods used, and to offer an alternative explanation for those data that does not rely on core knowledge of number. To that end, I will first review the literature on small number tasks, showing that what was once considered evidence for numerical understanding instead demonstrates infants' sensitivity to perceptual variables. I will next review the current literature on large number tasks in infants, paying particular attention to the method for controlling for perceptual variables. I then present data from two experiments showing that infants discriminate large sets on the basis of perceptual changes, not on the basis of number. In the final sections, I argue that the processes of attention and habituation are all that are needed to produce the patterns of looking behavior seen in infant number tasks.

SMALL NUMBER TASKS

Over the last two decades, developmental psychologists have gathered a wealth of knowledge on infants' knowledge of numbers by capitalizing on a behavior that even newborn infants can do: they can look. Infants, like all other animals, can also habituate, meaning declining responses to repeated presentations of a stimulus. Infant researchers have combined these two processes to ask infants what they know about a range of topics. In the

classic infant habituation paradigm, babies are shown displays of items or events repeatedly, and their looking time is measured. After many trials, infants indicate that they are no longer interested in the displays by looking less and less at each subsequent display. Then infants are shown new items or events, and again looking time is measured. If infants' looking times during the test items increases to the original levels, or if infants look longer at one test item compared to another, researchers infer that infants have detected a difference between stimuli.

This detection of novelty has been the basis for claims of deep conceptual knowledge in very young infants. Indeed, infants as young as 54 hours old have shown sensitivity to changes in small numbers of items (e.g., Antell & Keating, 1983), leading some to conclude that infants are born with a dedicated mental mechanism specific to number (e.g., Wynn, 1995). In order to probe the depth of this number sensitivity, researchers have approached this question in three different ways: 1) simple discriminations among numbers of objects, 2) counting events, and 3) simple addition and subtraction.

The first step in determining whether infants have any kind of numerical understanding is to see if infants can tell the difference between small numbers of items. To address this, experimenters have habituated infants to pictures of two items or three items and then tested them on both numbers. Across several studies, using identical or different items, testing infants ranging from 54 hours old through 12 months, and controlling for spatial layout, the robust finding is that infants look longer at the change in number than at the original number (e.g., Antell & Keating, 1983; Starkey, Spelke, & Gelman, 1990; Starkey & Cooper, 1980).

The second line of research has explored whether infants can count simple events. This requires a more complex understanding than the simple discriminations just described, in that those displays were all static pictures. In the first study to explore this, Wynn (1996) habituated infants to a puppet jumping either two or three times, with the rate and duration of the jumps controlled. During the test trials, infants saw alternating sequences of the puppet jumping two and three times. Infants looked significantly longer at the novel number of jumps, regardless of whether there was a pause between jumps, and regardless of different combinations of movements, such as jumps and falls (Sharon & Wynn, 1998). Together, these two studies led Wynn to conclude that infants can count events.

Given that infants can discriminate small sets and can count up to three, the third line of studies asks whether infants can calculate the precise results of simple mathematical problems (e.g., Wynn, 1992). To do this, 5-month-old infants faced an empty stage, where they first saw a hand lowering one doll into the stage. Then a curtain was lowered, and infants saw a second doll waved above the stage before it disappeared behind the curtain as if it were being placed in the stage. This was described as an addition problem: the first doll was placed in the stage, then the second doll was added to the first, 1+1. The curtain was then raised to reveal one of two alternating answers, one correct and one incorrect. For the "correct" outcome, infants saw two puppets, 1+1=2. For the "incorrect" answer, infants saw only one puppet, 1+1=1. Wynn (1992) hypothesized that infants would look longer at the impossible mathematical outcome, because infants would understand that this was incorrect. Infants did look longer at the impossible outcome. This finding has been replicated several times (e.g., Simon et al, 1995; Uller et al., 1999, but see Wakefield, Rivera, & Langer, 2000 for a failure to replicate).

Many researchers have treated these results as compelling evidence of sophisticated mathematical abilities in very young infants. Indeed, the reports of these studies have led to widespread acceptance of the idea that young infants have precocious understanding of

number. To understand the mechanism underlying these abilities, researchers have proposed two different kinds of models of infant number sense. The accumulator model, proposed by Wynn (1995; 1998), is based on Meck and Church's (1983) model designed to explain rats' sensitivity to both number and timing. Meck and Church trained rats to press a lever on one side of the cage after many (eight) flashes of a light or tone, and to press a lever on the other side after only two flashes. But here, number and duration co-varied (i.e., it takes longer to flash eight times than two times). The rats were then tested on either four flashes that varied in total duration, or a variable number of flashes that lasted four seconds. They found that the rats were able to generalize their responses in both conditions, regardless of their training. So rats trained on number were able to generalize to timing, and vice versa. Thus, Meck and Church (1983) posited that animals must use the same mechanism for both timing and counting. They proposed that that mechanism is an accumulator, which is a general mechanism involving a series of gated containers, like cylinders, that fill up with pulses that are emitted at a constant rate. When the accumulator is counting, each item counted receives one pulse, which then fills up the cylinder. When the accumulator is timing, the cylinder receives continuous pulses until the timing stops, at which point the gate closes, like a stopwatch. The fullness of the container then represents the total quantity or the total duration. Note that under Wynn's version of model, infants only have access to the final fullness of the cylinder, or cardinality of the set.

In contrast, the object-file theory focuses on infants' spatial representations of objects (e.g., Hauser & Carey, Simon, 1997; Scholl & Leslie, 1999; Feigenson et al., 2004). In this model, infants attend to individual objects during the tasks. When infants are presented with a display, they tag each item, forming a temporary mental representation of each one, called "object files". These files do not contain any other information; they merely act as a pointer for each individual object in the display (Trick & Pylyshyn, 1984; Leslie et al, 1998). Then, infants use one-to-one correspondence to compare the number of remembered tokens with the number of items in front of them during the test display.

Both theories assume that infants' discriminations in small number tasks are based on discrete number. The accumulator model proposes that infants can represent the total number of items in the habituation events, remember it, and then compare the fullness of the accumulator during the test trials to a second accumulator's fullness during habituation. The object-file theory posits that infants tag each item (whether it be tagging individual items in a static display or the number of puppet jumps), remember the tags, and then compare on a one-to-one basis the number of items tagged during the test trial.

However, there is an alternative to parsing these displays on the basis of discrete number. Changing the number of items or events in a display also impacts how much 'stuff' there is to look at, or how much time something interesting is happening (i.e., puppet jumps). A third model of infant behavior in small number tasks focuses on these perceptual changes in the displays. Specifically, the perceptual account proposes that infants' discriminations in all these tasks are based on sensitivity to changes in continuous variables, such as area and duration. Indeed, many recent studies have found that when these continuous variables are strictly controlled, infants show no sensitivity to changes in number, across all three lines of evidence described earlier (e.g., Clearfield & Mix, 1999; Clearfield, 2004; Feigenson et al., 2002).

Focusing first on the static visual displays, where infants are asked to discriminate numbers of items, it is important to note that the change from the habituation to the test

displays was more than simply adding or taking away one item. There was also a change in the overall amount of stuff to look at, both in terms of area and edge length. Adding a third dot to the display also added more black-to-white contrast around the perimeter of that new dot, as well as more black overall on the page. To explore whether these amount changes could account for infants' behavior, Clearfield & Mix (1999) pitted a change in amount directly against a change in number. They did this by habituating infants to two or three squares, all of the same size, and then testing infants on alternating two bigger squares where the total edge length was equal to three of the habituation squares or three smaller squares where the total edge length was equal to the two habituation squares. Infants looked significantly longer at the change in amount (the 2 bigger squares), and did not dishabituate to the change in number (the 3 smaller squares). This finding has been replicated, and has also been extended to different measures of amount such as area (Clearfield & Mix, 2001; Feigenson et al., 2002).

Similarly, infants' looking at the counting events can be explained without counting. A close examination of the method behind the jumping displays reveals that all of the jumps lasted the same amount of time. Thus, adding a jump or subtracting a jump changed the amount of time that the puppet was in the air moving. This is especially critical because any time that the puppet was not jumping, it was stationary on stage, and thus did not attract interest. And it is well-known that infants are sensitive to motion from a very early age (e.g., Dermany, McKenzie, & Vurpillot, 1977). The critical question then is whether infants' discriminations were based on the number of jumps or the amount of time the puppet spent jumping. To answer this, Clearfield (2004) pitted number directly against timing by habituating infants to the same jump sequence used by Wynn (1992). At test, infants saw two alternating displays. In one, the number of jumps was the same as habituation, 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. 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. Infants dishabituated to the change in jump time, but not to the change in number. This result suggests that perceptual cues, such as rate and motion, are more salient to infants than number. Further, perceptual cues may explain earlier findings previously attributed to enumeration (i.e., Wynn, 1996).

Finally, continuous variables can also account for the addition/subtraction studies. Recall that infants viewed one puppet being placed on the stage, then a curtain fell, and then a second puppet was lowered into the stage. Infants then saw alternating trials of one doll (the incorrect answer) and two dolls (the correct answer). But here too, if infants are sensitive to amount of doll, they should look longer at the unexpected amount of doll, which in this case is the incorrect answer. One small doll plus a second small doll should result in more doll than one of the same small dolls. Indeed, when the size of the doll was manipulated, infants looked longer at the change in doll size, rather than the change in number of dolls (Feigenson et al., 2002).

Thus, across all the different lines of evidence, slight changes in the displays led to dramatic changes in patterns of looking behavior. These findings offer a very different explanation for why infants looked longer at some displays than others, where attention to perceptual variables is enough to explain infants' looking patterns. This attention to perceptual properties could work in different ways. In the first, infants could form representations of amount. Indeed, later variations of the object-file theory posited a second

level of representations that included physical information about the displays. In contrast, infants could attend to perceptual variables like edge length and area without having any representations at all. Instead, sensitivity to these properties could arise out of the structure of the visual system. In particular, there are two types of retinal ganglion cells: the M ganglion cells and the P ganglion cells, which project their axons to the Magnocellular and Parvocellular layers of the lateral geniculate nucleus (LGN) (Leventhal, 1979; Perry, Oehler and Cowey, 1984). The M ganglion cells activate in the presence of motion, and the P ganglion cells respond to contrast, like that provided by edges. Infants' detection of change in contrast (amount of edge length) and motion (jump time) could result directly from the function of specific retinal cells. The neurological model is a perceptual model, positing that infants would be able to detect perceptual changes in these displays without having to count or understand anything about number. Thus, infants' discrimination might very well be perceptual in nature, rather than demonstrating a sensitivity to number.

Both of the representational models are challenged by this collection of results demonstrating attention to perceptual changes in the displays. Both models propose that infants have a conceptual understanding of number. But if these number mechanisms are robust, then slight changes to the perceptual (not conceptual) features of the display should not interrupt numerical processing. And neither model can easily account for attention to perceptual properties of the displays. The accumulator model can count discrete items/events, or it can measure continuous timing. But can the accumulator track continuous amount? The only way this could happen is if the accumulator kept track of the time needed to scan the displays. But if this is how it works, why wouldn't it work that way for number? That is, why have two separate ways of keeping track of quantity? And, as Mix, Huttenlocher and Levine (2002) point out, this mechanism has never been proposed. Similarly, the original object-file theory specifically posits that while infants tag individual items, no physical information about each item is in the object file. In order to attend to continuous amount, infants must be privy to those continuous variables. Later versions of this theory propose a second level of representation, where physical characteristics of each individual item are stored, and then processed (e.g., Feigenson et al., 2002). Although this ad hoc addition can address the amount data, this explanation is decidedly unparsimonious. If infants are attending to the physical characteristics of the display, and they can do this without having mental representations of each item, why require the mental representations?

In sum, although infants are sensitive to small quantities, it is not due to a sophisticated understanding of number or objects or even amount. Instead, infants' looking patterns arise from the interaction between the perceptual characteristics of the displays and visual attention.

LARGE NUMBER TASKS

More recently, numerous studies have tested infants on similar tasks with large numbers.

So far, the bulk of the data has focused on simple discriminations of large numbers, although there is one study of infants "counting" sounds (Lipton & Spelke, 2003) and one of "addition" and "subtraction" (McCrink & Wynn, 2004). In this section, I will focus on the

discrimination data because there are multiple experiments that replicate and extend each other.

Several recent studies have found evidence of large number discrimination in 6-month-old infants (Xu, 2003; Xu and Spelke, 2000; Xu, Spelke, and Goddard, 2005; Brannon et al., 2004). Using the simple habituation procedure, 6-month-old infants have successfully discriminated some large number sets, but not others (see Table 1). The pattern of successes and failures suggests that infants' large number estimations are inexact, requiring a 1:2 ratio. However, their precision improves with time, and some evidence suggests that by 10 months of age, infants can discriminate at a 2:3 ratio (Arriaga & Xu, 2004).

Table 1. Infant looking patterns for large number discrimination tasks

Successful Discrimination	Failure to Discriminate
4 vs. 8[1]	2 vs. 4[1]
8 vs. 16[2 3 4]	8 vs. 12[2 3]
16 vs. 32[3]	16 vs. 24[3]

[1] Xu, 2003, [2] Xu and Spelke, 2000, [3] Xu, Spelke, and Goddard, 2005, [4] Brannon et al., 2004

This collection of findings has led to proposals for two number systems, one for small numbers and a second for large numbers (e.g. Xu, 2003; Xu and Spelke, 2000). I have already described the possibilities for the small number system, which include the accumulator model, the object-file theory, and the perceptual account. For the large number system, most researchers have proposed the accumulator model (Xu, 2003; Feigenson et al., 2004). Recall that the accumulator represents numbers of items as sets, rather than individuals, and thus can account for approximate number. Importantly, discrimination of large numbers is in accordance with Weber's law, which explains the different findings based on the proportional difference.

Again, the theoretical explanations are all based on the assumption that infants are discriminating on the basis of number, not on the basis of perceptual variables. Researchers claim to have taken great pains to control for all continuous variables. In order to control for spatial layout, brightness, and surface area, researchers employed a very different method of control than those used in the small number tasks. In particular, every large number discrimination study to date has controlled for continuous variables in the same way: they presented habituation displays with different areas revolving around an average, such that each habituation display had dots of different sizes. Then both test trials differed equally from that average area, and from each other (see Figure 1 for an example from Xu & Spelke, 2000). The authors argue that this type of control renders amount information useless, forcing attention to number, which is the invariant feature across habituation trials. And then, since both test trials differ from the average amount of the habituation trials, infants should not be able to discriminate on the basis of amount. At the very least, if infants did attend to amount, they should dishabituate to both test trials.

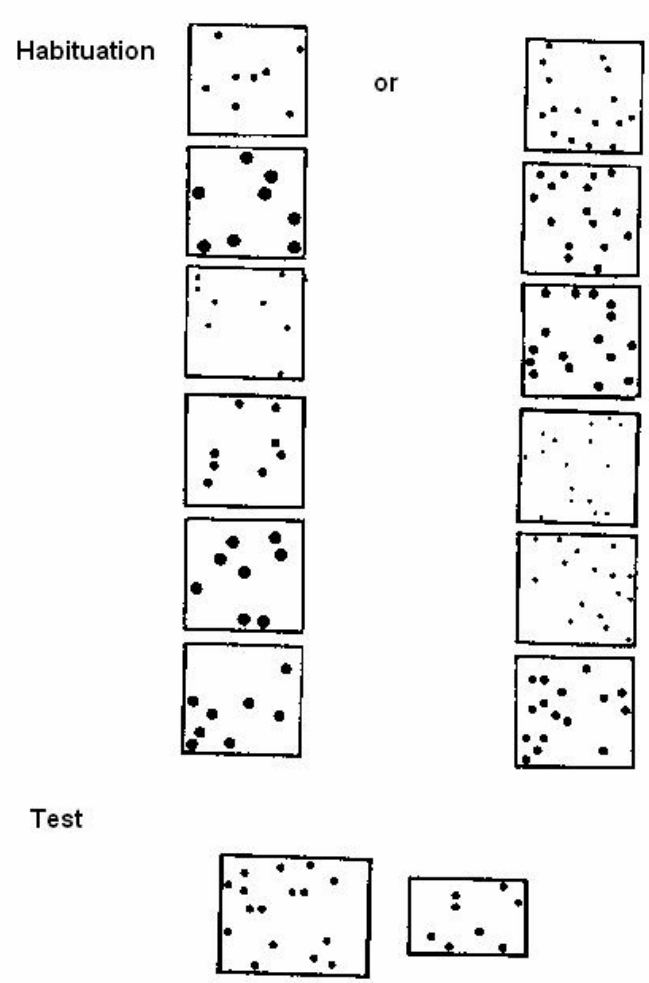
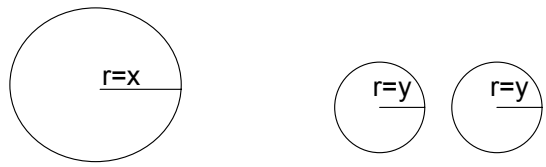


Figure 1. Habituation and test displays from Xu & Spelke's (2000) Experiment 1. Reprinted with permission.

It is worth noting that although infants could dishabituate to both test trials, no published studies report this particular statistic. Instead, researchers compared looking times between the two test trials, finding that infants looked longer at the change in number. Without reporting whether infants dishabituated to both displays, we cannot know if infants did indeed attend to the change in area presented in both test trials.

Leaving this concern aside, there is a much greater problem with this method of control. Simply put, it is mathematically impossible for this methodology to rule out the possibility that infants base their discriminations on perceptual variables. Recall that the researchers claimed that they have controlled for all continuous variables. However, within any particular set of items, if the number changes while the area and shape remain the same, the edge length *must* change. Consider the following overly simplified example (see Figure 2). Assume that we are trying to control area and contour length between one large circle and two smaller circles. Focusing on the left side of the figure, we see that the radius of the large circle is exactly equal to that of the two small circles added together. So we have now controlled for circumference. But what happens to area when circumference is controlled? Area is twice as

large for the large circle than for the two small circles, with the circumference controlled. Similarly, as shown on the right side of the figure, if area is controlled, then the circumference of the large circle is about half of the circumference of the 2 small circles. Thus, it is mathematically impossible, using the above-described method, to keep both area and edge length (or circumference) the same, without changing shape (which was not done).



Same circumference:

$2\pi X = 2[2\ \pi Y]$

$X = 2Y$

Same area:

$\pi X^2 = \pi(2Y)^2$

$X^2 = 2Y^2$

$X = \sqrt{2}Y$

Impact on area:

Big		Little
πX^2		$2\pi Y^2$
$\pi(2Y)^2$		$2\pi Y^2$
$4\ \pi Y^2$	$\neq$	$2\pi Y^2$

Impact on circumference:

Big		Little
$2\pi X$		$2[2\ \pi Y]$
$2\ \pi\sqrt{2}Y$		$4\ \pi Y$
$2\ \pi\sqrt{2}Y$	$\neq$	$4\pi Y$

Figure 2. The geometry of controlling area and contour length in circles while changing number.

Indeed, to follow through with this example to the precise calculations used in the first experiment of this kind, Xu & Spelke (2000) report that during the habituation trials, infants saw 8-dot displays with a revolving area around an average diameter of 1.83 cm or 16-dot displays with a revolving area around an average diameter of 1.3 cm. Infants were then tested on 8-dot and 16-dot displays with a 1.5 cm diameter. Table 2 shows the area and edge length for the individual dots within a display, as well as the complete displays for both habituation and test trials. Area was controlled for, as is clear from the 6th column. The average areas of both the 8-dot and 16-dot habituation displays are similar, and each test display differs from the habituation displays by about the same amount. However, notice the changes in edge length highlighted in the 7th column. The infants in the 8-dot habituation condition saw a slight decrease in edge length on the 8-dot test trial, but the 16-dot test display nearly doubled the edge length from habituation. Similarly, the infants habituated to the 16-dot display saw a very similar edge length in the 16-dot test trial, but the 8-dot test trial's edge length was nearly half of the habituation trials.

Table 2. Area and edge length (in cm) of habituation and test displays in Xu & Spelke (2000)

	Individual Items			Display Total	
	Avg. Diameter	**Surface Area**	**Edge Length**	**Surface Area**	**Edge Length**
Habituation Displays					
8	1.83	2.63	5.75	21.04	*45.99*
16	1.3	1.327	4.08	21.24	*65.34*
Test Displays					
8	1.5	1.77	4.71	14.14	*37.69*
16	1.5	1.77	4.71	28.27	*75.39*

Thus, in Xu & Spelke's displays (and those of all the other researchers using this method of control), edge length was hopelessly confounded with number. And as described above, infants are highly sensitive to changes in edge length. With this confound, it is impossible to determine the basis of infants' looking preferences. This is a critical question, because most other findings have been explained with perceptual accounts. Thus, it is imperative that we determine whether number is indeed the underlying basis for infants' looking preferences in large number tasks.

AMOUNT VS. NUMBER IN TWO LARGE NUMBER EXPERIMENTS

As noted above, infants have discriminated large sets when they differed on a 1:2 ratio, but not 2:3 (Xu & Spelke, 2000; Xu, 2003; Brannon et al., 2004; Xu, Spelke & Goddard, 2005). Here, I present two experiments designed to determine whether infants base these discriminations on the difference in number or the change in total amount (i.e., edge length). Unlike previous research that allowed the size of the discs to vary across habituation trials, edge length was allowed to covary with number during habituation (keeping all the discs the same size across all habituation trials), and then separated at test, such that infants could respond to a change in edge length, number, or both. The first experiment tested infants' discriminations of 8 vs. 16, and the second tested 8 vs. 12.

Experiment 1

Participants

This study included 16 infants (9 females, 7 males) with a mean age of 6.32 months (range = 4.73 to 6.8 months). One additional infant was excluded for failure to habituate. All infants included in the study reached criteria for habituation. Infants were recruited through local published birth announcements and then contacted by mail. All families received a small gift for participating.

Design

During habituation, infants saw a series of displays with either eight or sixteen squares. The individual squares were the same size across displays, but the arrangement of the squares varied randomly. At test, four alternating displays were presented (see Figure 3). Two of the test displays had the same edge length as the habituation displays, but contained a novel number of squares (either 8 or 16). The other two test displays contained the familiar number of squares with a novel edge length. The edge length change was the same as if the squares had stayed the same size and either doubled or halved in number. For example, if infants were habituated to 8 squares with 1 cm sides (i.e., a total edge length of 32 cm), then the edge length change test display had 8 squares with 2 cm sides for a total edge length of 64 cm — the same edge length that 16 squares with 1 cm sides would have. The number change displays always alternated with the edge length change displays, but which one infants saw first was counterbalanced across infants.

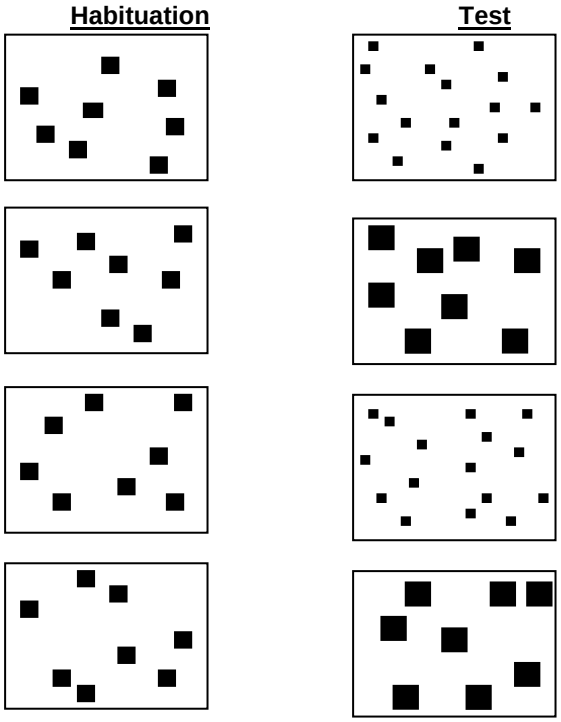


Figure 3. Sample habituation and test trial displays for Experiment 1.

Because previous research has indicated that infants respond to changes in area, edge length, or both, the present study did not attempt to separate these dimensions. However, because edge length and area are not perfectly correlated, this means that both test displays differed from the habituation displays in terms of area. Specifically, the ratio of the habituation and test displays in terms of area was 1:2 in the number change condition and 1:4 in the edge length change condition. As one would expect, the difference was much greater in the edge length change condition. Nonetheless, this design made it possible for infants to dishabituate to both test displays based on the area change. As we will see, however, this pattern of results was not obtained.

Apparatus

Infants viewed the displays on a lighted black stage in a small quiet room. The stimulus displays were computer generated drawings of black squares on a 21.5 x 28 cm white background. Hard copies of these drawings were mounted on foam board to create cards that could be slid in and out of the stage area. A wooden stopper was attached to the far end of the opening to ensure that the display cards were placed at the same location for every trial. One experimenter presented the stimulus cards while a second 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 the average looking time decreased by half. The computer then signaled the first experimenter to begin the test trials. In this way, the experimenter who recorded looking times was blind to the onset of the test trials. Infants' faces were videotaped for later coding.

Procedure

Infants sat on their parents' lab at a distance of 60 cm from the stage opening. Although earlier studies had infants watch displays in an infant seat, those studies also suffered from high rates of attrition due to fussiness. To avoid this, infants were held by their parents, who were instructed to keep their eyes closed and not to interact with their infants (videotapes confirmed that parents followed these instructions). Trials began as soon as the infant had fixated on the display and lasted for 10 seconds. Habituation displays were presented until either the infant habituated by the criteria described above, or for a maximum of 16 habituation trials. Infants were then shown the four alternating test trials.

Results

To ensure the reliability of the on-line coder, a second coder blind to the experimental conditions measured looking times from 20% of the videotaped sessions. Inter-rater agreement was high (90.2% exact agreement; Pearson's $r=.91$) so the on-line recordings were used in all subsequent analyses. A preliminary analysis of variance (ANOVA) indicated that looking times did not differ by test trial order or the number of squares that infants saw during habituation (8 or 16). Therefore, the data were collapsed across these variables for subsequent analyses.

To address whether infants dishabituated to changes in edge length, number, or both, infants' looking times on the last habituation trial were compared to the average looking times for each type of test trial. The infants showed significant recovery of attention when the displays changed in edge length, $t(15)=4.76$, $p<.001$, but not when the displays changed in number, $t(15)=.66$, n.s (see Figure 4). Moreover, the differences in infants' looking times for the two types of test displays was significant, $t(15)=4.23$, $p<.001$. Thus, as in similar research on small sets, infants detected the change in amount, but not the change in number (e.g., Clearfield & Mix, 1999).

One could argue that infants only responded to the change in amount when it was pitted directly against number. That is, because the test trials alternated a number change with an edge length change, the results may reflect a preference for the change in amount. By this reasoning, if an amount change had not been presented, infants might have responded to the number change. Of course, there was no reason that infants could not dishabituate in both test

conditions. Furthermore, the lack of a significant order effect casts doubt on this interpretation. However, we can be sure that the failure to dishabituate to number was not simply due to an amount preference by analyzing the first test trial looking times between subjects. On the first test trial, half of the infants saw the number change and half saw the edge length change. There was no choice involved at this point because there was no way for infants to anticipate another display with a different type of change. When looking times were compared to those on the last habituation trial, the same general pattern emerged. Infants looked significantly longer at the amount change, $t(7)=5.03$, $p<.01$, but did not dishabituate to the change in number, $t(7)=.65$, n.s.

In sum, the present experiment indicates that infants discriminate changes in large sets in the same manner they discriminate small sets—based on changes in overall amount, not number. This finding directly contradicts that of Xu & Spelke (2000), who attempted to strictly control for amount. They found that 6-month-old infants responded to the change in number, not the change in amount. However, a likely explanation for this discrepancy is their method of controlling amount. As described above, their control method confounded changes in edge length with changes in number. When these were properly controlled, infants responded to the change in edge length.

Some researchers have argued that infants can estimate the number of items in large sets, but because those estimates are inexact, they only support discriminations of highly discrepant sets (Xu & Spelke, 2000; Xu, Spelke & Goddard, 2005). Consistent with this interpretation, infants in previous research have discriminated 8 from 16 and 16 from 32, but not 8 from 12 or 16 from 24. However, the results from Experiment 1 indicate that infants use overall amount rather than number to detect the difference between 8 and 16. This raises the question of whether infants might also use amount to detect the difference between 8 and 12.

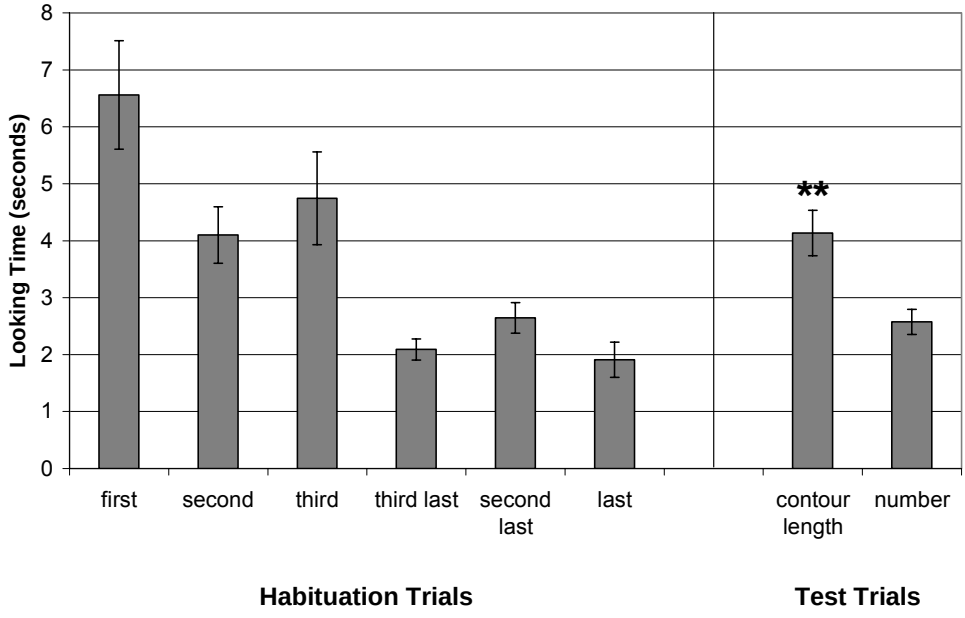


Figure 4. Mean looking times across the first three and last three habituation trials and the test trials for Experiment 1, 8 vs. 16. ** $p < .001$.

Experiment 2

Participants

An additional 16 infants (9 males, 7 females) with a mean age of 6.29 months, (range = 4.83-7.63 months) participated. One additional infant was excluded due to fussiness. All infants reached criteria for habituation. Infants were recruited through local published birth announcements and then contacted by mail. All families received a small gift for participating.

Design, Apparatus and Procedure

This experiment used the same design, apparatus and procedures as Experiment 1. The only change was that the displays contained either eight or twelve squares during habituation, and the test displays consisted of alternating displays of eight and twelve squares.

Results

To ensure the reliability of the on-line coder, a second coder blind to the experimental conditions measured looking times from 20% of the videotapes. As in Experiment 1, inter-rater agreement was high (92.9% exact agreement; Pearson's r=.90) so the on-line recordings were used in all subsequent analyses. Because looking times did not differ by test trial order or the number of squares infants saw during habituation (8 or 12), the data were collapsed across these variables.

The critical question of Experiment 2 was whether infants dishabituated to changes in edge length, number, or both. Again, infants' looking times on the last habituation trial were compared to the average looking times for each type of test trial. The infants showed significant recovery of attention when the displays changed in edge length, $t(15)=8.74$, $p<.001$, but not when the displays changed in number, $t(15)=1.39$, n.s. (see Figure 5). Further, the differences in infants' looking times for the two types of test displays was significant, $t(15)=6.36$, $p<.001$.

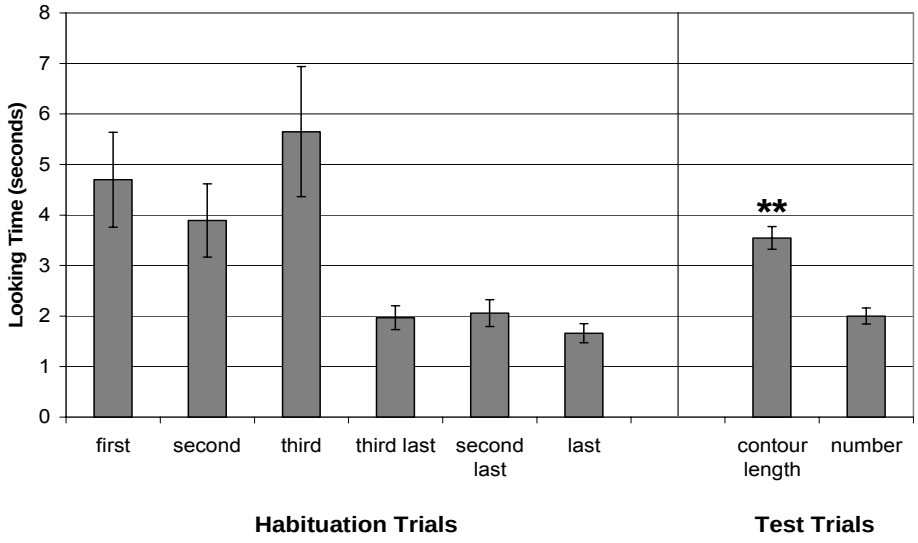


Figure 5. Mean looking times across the first three and last three habituation trials and the test trials for Experiment 2, 8 vs. 12. ** p < .001.

Thus, infants detected the change in amount between two large sets even though the ratio was 2:3 rather than 1:2. This finding is inconsistent with the conclusion reached by Xu and Spelke (2000)—namely that infants could not discriminate between large sets this close in number. However, recall that those authors analyzed only the difference in looking toward the two test displays when both were equidistant from the average area of the habituation displays. Thus, it is possible that infants dishabituated to both test displays based on the change in amount.

To ensure that infants did not respond to the change in amount merely because it was pitted directly against number—that is, as a preference for amount when given a choice—I compared their looking times on the first test trial to those on the last habituation trial. On the first test trial, there was no way for infants to know that a change in the other dimension would be presented next. Nonetheless, the same pattern was obtained as when all the test trials were included. On the first test trial, infants dishabituated to the change in amount, $t(7)=4.67$, $p<.01$ but not the change in number, $t(7)=1.51$, n.s. Thus, infants discriminated between large sets even when the ratio was 2:3, and the basis for their discrimination was continuous quantity.

These data pose a significant challenge to the accumulator, two-system model of infant numerical processing. Just as the accumulator couldn't process amount over small numbers, it can't process amount over large numbers either. The model claims to be inexact with respect to number, but it still requires adding up the number of pulses that end up in the accumulator during habituation, and then comparing that fullness of that accumulator with a second accumulator during the test trials. And the fullness can only come from duration (not relevant here) or number, not amount.

In contrast, the data suggest attention to continuous amount is an important factor in infants' looking preferences. The results of both experiments provide a consistent explanation for infants' behavior in a range of discrimination tasks. The present results show that when amount is properly controlled in any number visual habituation task, infants attend to changes in amount, not number. This finding is consistent with previous work using small sets (Clearfield & Mix, 1999; 2001; Feigenson, Carey & Spelke, 2002) and suggests that rather than representing any of these quantities in terms of number—either approximate or exact—young infants respond to them all in terms of overall amount.

Why, then, did infants fail to make the 2:3 large set discriminations in previous research (Antell & Keating, 1983; Starkey & Cooper, 1980; Xu & Spelke, 2000; Xu, Spelke & Goddard, 2005)? Again, a close examination of the changes in edge length demonstrates that those changes are smaller with the smaller proportional difference. It appears that the change in edge length needs to be large enough that infants can attend to it, and with large numbers of items, a 2:3 ratio doesn't reach that criteria of large enough difference.

This same explanation of changes in edge length can also explain Brannon et al's (2004) second experiment, where they habituated infants to varying numbers with a constant amount. The numbers ranged from 3 to 15, but the area remained constant for each trial, thus attempting to force attention to amount rather than number. Then infants were tested on alternating trials of new numbers with an area equal to the average area of the habituation trials. In this case, infants showed no preference for either test trial. Brannon et al concluded that "infants do not form a representation of a given surface area when it requires summating area over variable numbers of discrete elements and ignoring large changes in number" (p.B67). However, changes in edge length were again not controlled, and can account for the

lack of preference for either test trial. Specifically, with edge length dramatically changing on every single habituation trial, infants would not be able to attend to it, and then would not be able to demonstrate a novelty preference. Indeed, it is likely that infants would not habituate at all, which is exactly what Brannon et al (2004) report (almost half the infants failed to reach habituation criterion). If infants don't habituate, a lack of novelty or familiarity preference is expected.

BEYOND METHODOLOGY: A DYNAMIC ACCOUNT OF INFANT LOOKING BEHAVIOR

Some have asked whether this perceptual account simply represents a methodological nitpick, and whether time and resources might be better spent truly exploring the limits of infants' numerical knowledge. I believe the nature of this question reflects fundamental differences in thinking about infant knowledge and development. This kind of question is representative of a common way of thinking about infants' behavior in looking tasks. The thought is that looking is a window into infants' minds, and if we could just strip away all of the perceptual "noise", we can uncover infants' true conceptual understanding. In this mindset, focusing on small perceptual changes in the displays does seem like nitpicking.

However, these perceptual changes have a huge influence on infants' preferences for familiar or novel test displays, as seen in the present data as well as a number of other studies (e.g., Clearfield & Mix, 1999; 2001; Clearfield 2004; Clearfield & Westfahl, in press; Schilling, 2000; Thelen & Schoner, in press). These perceptual influences on novelty/familiarity preferences become critical when the entire body of literature on infants' number sense is based on looking procedures. Indeed, nearly every study investigating infants' understanding of number uses either a habituation or familiarization procedure. In both methods, infants are shown some kind of visual display, either a few times or many times, and then infants are shown other displays, and looking time is measured. Statistics are then run to see what kind of display infants looked at longer. In other words, was there a group novelty or familiarity preference?

Despite the wealth of evidence for the flexibility of familiarity/novelty preferences, developmental psychologists have shown little restraint in going from novelty preferences in looking behavior to claiming innate conceptual knowledge. For example, Xu & Spelke (2000) claim, on the basis of the results examined here, that "a sense of number exists in human infants by 6 months of age" (p.B7). Similarly, Wynn (1995) states that "…human infants possess extensive numerical competence…not based on perceptual properties of displays…" (p.35).

The problem with these claims is that it is difficult to know why infants demonstrate a familiarity or novelty preference. Familiarity and novelty preferences are highly sensitive to slight changes in the parameters of the displays. These changes may not always be obvious, but may significantly alter the outcome of any particular experiment. This makes it extraordinarily easy to obtain any desired result, which can then support any claim about infants' knowledge. Moreover, although researchers can claim that their displays are about addition or causality, there is no way to know what the infants think the display is about. For example, Wynn (1992) claimed that her puppet show procedure was an "addition" problem,

with 1 puppet being added to another puppet, and then the experimenter revealing either the correct or incorrect "answer". However, it is not at all clear that infants see these puppet shows as a coherent addition problem. Clearfield and Westfahl (in press) demonstrated that showing infants one doll was no different from showing them 1+1=1, and showing infants 2 dolls was no different than showing them 1+1=2. Instead, it appeared that infants focused on whatever number of dolls remained on the stage, and ignored all of the hand waving and putting dolls in or taking them out of the stage. This suggests that infants don't construe these puppet shows as a mathematical problem.

That finding is very important, because it demonstrates that experimenters don't always know on what aspects of their displays the infants focus. All we can state with certainty is that when a 6-month-old infant watches a display, the processes of visual perception and attention are at work. As Schöner and Thelen (in press) eloquently state, "[t]hose who claim their displays are just about content—be it number, object properties, or causality—must, we believe, tell us at what point a display ceases to obey basic visual and attentional processes and crosses a line into pure meaning" (p.45-6).

Indeed, these processes alone have explained large bodies of classic literature in infant development, including infants' understanding of object properties as demonstrated in infant perseverative reaching tasks (Thelen, Smith, Schoner & Scheier, 2001) and infants' understanding of causality, as demonstrated in Baillargeon's habituation procedure (Thelen & Schoner, in press). The challenge facing developmental psychologists now is to understand the processes that produce behavior in the particular kinds of tasks that we use with infants. It is not enough to make a conceptual claim from longer looking at a novel event. We need to understand the complex processes underlying looking behavior in general, and we need to determine why infants look longer at some events compared to others. Indeed, we need to understand the processes of habituation and dishabituation that produce the behavior that we then interpret.

To that end, I propose that the natural extension of the perceptual explanation for numerical understanding comes from the dynamic field model (Thelen & Schoner, in press). The main idea is that infants' behavior in these number tasks can be attributed to perceptual attention and the processes of habituation. The key contribution of the model's explanation is that, like the perceptual-based small number explanation, it doesn't require any conceptual knowledge. Instead, infants' behavior is explained by the dynamics of looking.

THE DYNAMIC FIELD MODEL OF HABITUATION

The dynamic field model of habituation is a version of what is known as field theories. These are a general class of time-based models that integrate environmental input along a continuum of dimensions to reach an action decision. The foundation of these theories is that the decision to act is based on both the immediate environmental stimuli, as well as the history of the system in similar situations, both short-term and long-term history. The stimuli are then converted into inputs of varying metric dimensions, and then the inputs are integrated in a decision field, where a high level of activation (above threshold) results in behavior. The challenge for modeling a behavior is determining the different inputs to the decision field, and at what level the decision field activation reaches the threshold to act.

These models have been used to describe many complex behaviors, including location memory (Spencer & Schöner, 1998) and infant perseverative reaching (Thelen, Schöner, Scheier, & Smith, 2001). Critical to these applications are the assignment to the stimuli of continuous metric variables which assume different activation strengths. Note that the continuity of the variables allows for measures of the perceptual similarity of one variable to another. Another critical component of these models is that they model behavior in real time. That is, they rely on the importance of the history of the system, both before entering the experiment, and over the course of each trial. These models assume that behavior on trial 1 will impact behavior on trial 2, and behavior on trials 1 and 2 will then impact behavior on trial 3, and so on.

In a habituation task, the decision to act is one where the infant decides whether to look towards or to look away from a display. The dynamic field model of habituation proposes two input fields that go into this decision (Schöner & Thelen, in press). These interacting input fields reflect any perceptual dimensions that enter into the decision to look. One input field is the activation field, which represents both the perceptual similarity of the stimuli and the strength of activation. In modeling terms, perceptual similarity refers to the metrics in perceptual space. In other words, stimuli that are more similar to each other will overlap in perceptual space. The level of overlap is related to the level of interaction, with more similar stimuli resulting in higher levels of interaction. The second input field is the habituation field, which represents the level of habituation to a particular stimulus. This field consists of inhibition variables, which receive input from the activation field. So the level of inhibition comes from the level of input from the activation field. These two fields feed into a decision field, with a threshold. When the input reaches the decision threshold, a look begins. When the input level drops below threshold, a look ends.

Schöner and Thelen (in press) tested this model using a series of simulations. They varied several parameters, including the time scales of both the activation and inhibition fields and the threshold levels, and tested under what conditions was the activation above the decision threshold. In other words, under what conditions were there looks, and how long did the looks last?

Habituation Trials

With respect to habituation trials, there were two especially relevant findings. The first concerns the timing of the stimulus displays. In the field model, the looking field rests when there is no stimulus present. This means that the inter-stimulus interval (ISI) is critical. The activation levels for a 5 second ISI between the first and second presentation look very different from a 30-second ISI. Specifically, the initial activation level is much lower for a longer ISI, and the inhibitory field is also weaker. This results in longer looking times over many trials, thus dragging out the habituation process. Quicker presentations of the habituation stimuli results in faster habituation.

The second critical finding for habituation is the importance of stimulus strength. Simply put, stronger stimuli result in higher activation at stimulus onset. This results in longer looking times for stronger stimuli. Stronger activation also leads to higher inhibition. However, as the stimulus strength gets very strong, the system fails to habituate. One

simulation showed no habituation after 15 trials. Schöner and Thelen state that in this case, activation simply overrides the inhibition, despite how high the inhibition is.

Dishabituation Trials

In order to simulate realistic test trials, Schöner and Thelen (in press) based the model's responses on Baillargeon's (1987) classic "drawbridge" study. The details of this study are not relevant to this discussion. Suffice it to say that the simulations successfully modeled the complex pattern of infant looking as reported by Baillargeon (1987). Again, there were two main findings from the simulations that are particularly relevant to the present discussion.

First, the strength of the activation is again critical. In Baillargeon's study, there is one change between the habituation and both test trials that is quite significant: the addition of a block. Schöner and Thelen argue that the additional stimulus increases the general activation of the system, which then interacts with the habituation field to produce either familiarity or novelty effects. High activation coupled with fewer habituation trials resulted in a familiarity effect, whereas high activation coupled with more habituation trials resulted in a novelty effect.

The other key factor in dishabituation is the amount of perceptual overlap between the habituation and test stimuli. In the prototypical habituation/dishabituation test, there is no overlap, which results in a strong novelty preference. However, in most infant studies, there is considerable overlap among both test trials and the habituation. Indeed, one test trial is designed to be perceptually familiar but conceptually incorrect, while the other is supposed to be perceptually novel but conceptually correct. The goal is to separate perceptual preferences from conceptual knowledge, so a simple perceptual novelty response would reflect a lack of conceptual knowledge. Infants would need to look at the perceptually similar display to demonstrate understanding of the concept. However, the dynamic field model predicts that to the extent that there is perceptual overlap, there will be increased activation, and therefore increased inhibition. The more similar the displays are, the less likely infants are to dishabituate because both the activation and inhibition fields are swamped. The simulations showed that the perceptual overlap indeed impacted familiarity/novelty preferences (Schöner & Thelen, in press).

APPLICATION OF THE DYNAMIC FIELD MODEL TO THE NUMBER STUDIES

In this section, I will apply the lessons learned from the dynamic field model to the large body of literature on infants' sense of number. Again, I separate the discussion into the two parts of each experiment: the habituation phase and the dishabituation phase.

Habituation Phase

As described above, there are two important factors that determine infants' looking patterns on the habituation trials: ISI and stimulus strength. ISI is simply not reported in any study. Indeed, it is usually not controlled. Instead, researchers rely on an infant-based procedure, where a trial ends after an infant has looked at the display for a certain amount of time and then looked away for a certain amount of time. But each study defines this differently, which should lead to dramatically different ISI's across studies. For example, Xu and Spelke (2000) began a habituation trial with the first ½-second look at the display, and ended the trial with the first 2-second look away from the display. Xu (2003) used a similar procedure, but also ended trials after 120 seconds maximum, while Brannon et al. (2004) imposed a 15-second maximum. Just the difference between these last two studies would cause enormous differences in ISI. Compare that to the procedure used by Clearfield (2004; Clearfield & Mix, 1999; 2001), in which a habituation trial began when the infant first fixated on the display, and lasted 10 seconds, whether the infant looked for 2 seconds or the entire 10 seconds. This kind of procedure would likely result in much faster ISI's than the other procedures, because once the first look begins, the trial ends 10 seconds later no matter what. In the former procedure, it generally takes multiple looks (which take time) to get to criterion. According to the model, this increases the likelihood of habituation in Clearfield's studies, and indeed, all infants in her experiments reached criterion for habituation. In contrast, the longer (and quite variable) ISI's for the earlier studies would drag out the process of habituation, resulting in longer looks at each trial, and many more infants not reaching criterion. This is exactly what happened — in the few studies that report rates of habituation, between 25% and 38% of infants failed to habituate (e.g., Brannon et al., 2004; Xu, 2003).

The second critical factor in the habituation process is stimulus strength. The field model predicts, and the simulations showed, that the higher the stimulus strength (i.e., the more complex the display), the higher the activation and the higher the inhibition. This leads to very long looks. And, when the stimulus strength is very strong, the high levels of activation override the inhibition, and the system fails to habituate, even after 15 trials. All of the large number discrimination studies (except for the present data) fit this description (Xu & Spelke, 2000; Xu, 2003, Xu, Spelke & Goddard, 2005; Brannon et al., 2004). The original four studies used highly complex habituation stimuli (see Figure 1). Recall that the method for controlling amount was to vary it on every trial. So each display that infants saw had many dots (ranging from 4 to 32), in random patterns, and the dots changed size and arrangement on each trial. And in the one experiment designed to elicit attention to amount, the amount of edge remained constant across habituation trials, but the number of dots changed, ranging from 3 dots to 15 dots. All of these are complicated displays, which should elicit activation levels so high that they swamp the system.

The importance of the complexity of these displays becomes clear when compared to infants' behavior in the simplified version of the large number task presented here. In these experiments, the size and number of squares on the habituation displays remained constant, and changed only at the dishabituation trials. All of the infants habituated. It is unclear to what extent the infants here habituated because of the shorter ISI's and how much was due to the simpler displays. For now, the key is that both of these factors have been theorized to impact the rate of habituation, both of these factors were different between the current experiments and the previously reported data, and the rates of habituation that were reported

in the present experiment and the previous studies were consistent with the model's predictions.

Dishabituation Phase

The most important lesson learned from the dynamic field model is that what infants look longer at during the test trials is completely determined by their activation and inhibition levels during the habituation phase. This is not conceptual in nature, but rather, infants' looking preferences are determined by the dynamics of the habituation procedure itself. According to the model, these differences in the habituation processes among studies could already account for the differences seen during the test trials. However, we can also draw on the model for explanations of the pattern of looking on the test trials.

The level of activation over trials depends on the metric scaling of some important dimension. I submit that the critical dimension is some measure of amount (edge length is a good candidate). Focusing first on the data presented above, keeping amount constant over the habituation trials enabled infants easily to attend to it, and habituate to the displays. At the test trials, one of the test stimuli, the change in number, was exactly the same amount as the habituation trials. This led to complete perceptual overlap, which prevented the activation from overcoming the inhibition. Thus, we saw no dishabituation to the change in number, across both ratios (8 vs. 16, and 8 vs. 12). The other test trial was a new amount with the familiar number. But since amount is the critical dimension, and there was a change in amount, there was no perceptual overlap. This resulted in a novelty response, or dishabituation. Thus, the model explains why infants looked longer at the change in amount compared to the change in number, and only dishabituated to the change in amount, and not to the change in number. This explanation is simple, parsimonious, compatible with the small number data, and arises from processes that we know exist in infants: visual attention and habituation.

Similarly, the pattern of large number discrimination findings previously reported in the literature can be explained in the same manner. Instead of number being the critical dimension as was previously claimed, edge length was again the critical dimension. As shown in Table 2, although area was controlled, edge length was not, and large changes in edge length coincided with the changes in number. If edge length of the individual elements is the critical dimension (and all evidence so far supports this), then the changes in edge length account for the longer looking times at the test trials. This explanation also makes sense of the proportional data, where infants failed to discriminate 8 from 12, because the difference in surface area between 8 and 12 is less than the difference in surface area between 8 and 16. Thus, more perceptual overlap and less novelty would result in no preference for either test event.

The dynamic field model can also account for some of the more complex displays used in both the small and large number studies. For example, Wynn's (1996) puppet jumping task involved familiarizing infants to two or three puppet jumps, and then testing them on both numbers of jumps. Infants looked longer at the change in number of jumps, across controls for rate and duration. Recently, Clearfield (2004) found that what infants attended to in this task was the amount of time the puppet spent jumping, not the change in number of jumps.

This explanation fits the model perfectly, because more or less time in motion would significantly affect levels of activation during both the familiarization and test phases.

The model also applies to the small number addition and subtraction findings. In this procedure, infants watched a puppet show purported to demonstrate correct and incorrect addition (1+1=1, 1+1=2) and subtraction problems (2-1=1, 2-1=2) (e.g., Wynn, 1992). In the original study, infants looked longer at the incorrect answer. Not only do infants change their looking behavior when the amount of doll is controlled (Feigenson et al., 2000), but infants also change their looking based on the familiarity or novelty of the test display (Cohen & Marks, 2002; Clearfield & Westfahl, in press). Specifically, Clearfield and Westfahl (in press) found that habituating infants to one or two stationary dolls before the "addition" problems significantly impacted their behavior. Infants who were habituated to one doll looked longer at the "correct" answer, which was two dolls on the stage after the puppet show. Infants who were habituated to two dolls looked longer at one doll on the stage, the "incorrect" answer. According to the model, infants habituated (high levels of activation with moderate levels of inhibition) to a particular amount of doll, resulting in a novelty response when the critical dimension (amount of doll) changed. Thus, it was not the mathematical outcome of the puppet show that determined infants' looking preferences, but rather what infants saw before they were tested. This is exactly what the model would predict.

A recent study by McCrink and Wynn (2004) reports evidence of large number addition and subtraction in 9-month-old infants. These displays were extraordinarily complex. There were no habituation trials in this procedure, but there was an occluder-familiarization movie, where a rectangle moved across the screen, rotated three times, was occluded, and then was revealed to be shrinking and growing and rotating. This was shown 5 times, after which infants saw two outcome-familiarization movies, which showed an occluder drop to reveal either 5 or 10 shapes. Then infants were tested on the entire addition or subtraction procedure, where infants saw five items (of all different sizes) moving across the screen, then an occluder slowly arose to hide those items, and then five more items moved across the screen behind the occluder. On the test trials, infants saw six alternating trials, three of the correct outcome and three incorrect. It should be apparent that according to the model, this level of complexity would completely swamp the system before the test trials.

CONCLUSION

In sum, the dynamic field model can account for the wide range of experimental findings, including small and large number tasks, visual discrimination, counting, and addition and subtraction. This model presents a parsimonious and coherent explanation that is grounded in processes that we know infants do: process visual stimuli, habituate, and dishabituate. Importantly, this model of behavior does not rely on higher-level abstract knowledge, but rather basic, known, perceptual and attentional processes.

This dynamic approach reflects a new way of thinking about infants' behavior in experimental tasks. Dynamic theories shift the focus away from what babies *know* to what babies *do*. The traditional view is that the performance measure—looking—gives us direct access to the mental concepts. But as long as our entry into infant cognition is through looking, the looking dynamics must be considered. The model clearly demonstrates that

where an infant looks must be the product of the particular sequence of visual events and the infants' immediate and long-term history of looking. The developmental history and real-time dynamics of the response cannot be separated from the constructs the response is designed to measure. As long as perception and action are viewed as only the bystanders in cognition, experimenters may wrongly attribute an enduring "competence" to what is always a dynamic interplay of mental and bodily processes embedded within a rich context.

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