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Infant arithmetic : a multiple variable approach.

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INFANT ARITHMETIC: A MULTIPLE VARIABLE APPROACH

A Thesis Presented

by

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CHAPTER I

INTRODUCTION

Looking time procedures provide a window into young infants' minds. Developmental psychologists have studied young infants' cognitive processing by measuring infants' looking times to a variety of possible and impossible events. The results of some of these studies suggest that infants as young as 3.5 months of age have object permanence (Baillargeon, 1987; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Baillargeon, Spelke, & Wasserman, 1985; Kellman & Spelke, 1983). However, others have questioned whether the looking time procedures used in these studies have measured cognitive processing or perceptual processing. Bogartz, Shinskey, & Speaker (1997) and others found that the results of some of the object permanence studies can be best explained by simple perceptual processing instead of cognitive processing (Bogartz & Shinskey, 1998; Bogartz, Shinskey, & Schilling, 2000; Cashon & Cohen 2000; Meltzoff & Moore, 1998; Rivera, Wakeley, & Langer, 1999; Schilling, 2000). Recently, similar looking time techniques have been used to study infants' mathematical abilities (Feigenson, Carey, & Spelke, 2000; Koechlin, Dehaene, & Mehler, 1997; Simon, Hespos, & Rochat, 1995; Uller, Carey, Huntley-Fenner, & Klatt, 1999; Wynn, 1992; 1995; Wynn & Chiang, 1998), and the results suggest that young infants have mathematical abilities. However, the results of these infant arithmetic studies may also be explained by perceptual processing rather than cognitive processing.

The landmark study of infant arithmetic was conducted by Wynn (1992) and has been replicated by many others (Koechlin et al., 1997; Simon et al., 1995; Uller et al., 1999). Similar procedures were used in these studies, and the results suggest that infants have mathematical abilities whether addition or subtraction is the operation. However, the finding is not robust (Feigenson et al., 2000; Wakeley, Rivera, & Langer, in press), and the events used in these studies are confounded with other variables. The present study investigates some of these confounds and presents a different interpretation for some of the infant arithmetic studies.

Wynn (1992) used a violation of expectation paradigm to test infants' arithmetic abilities. Her infants were shown an empty stage. To begin an addition trial, the experimenter introduced an item from the side of the stage, and the item was placed on the stage as the infants watched. A screen rotated up, occluding the first item, and a second item was then placed behind the screen while the infant was looking. On half of the trials the experimenter removed one of the items without the infant knowing; on the other half, the items were left untouched so that two items remained behind the screen. When the screen rotated down, there were either two objects on the stage ($1 + 1 = 2$), the possible event, or there was only one object on the stage ($1 + 1 = 1$), the impossible event, and looking time was measured. A trial concluded when infants looked away for 2 consecutive seconds after looking at the display for a minimum of 2 seconds, or had looked for 30 cumulative seconds.

To begin a subtraction trial, the experimenter introduced two items from the side of the stage. Both items were placed on the stage as the infants watched, and then a screen rotated up, occluding the items. The hand reappeared from the side of the stage and removed one item from behind the screen while the infant was looking. On half of the trials the experimenter replaced the item without the infant knowing so that two items remained behind the screen; on the other half, the item was not replaced so that one item remained behind the screen. When the screen rotated down, there were either two items on the stage (2 – 1 = 2), the impossible event, or there was one item on the stage (2 – 1 = 1), the possible event, and looking time was measured.

Wynn hypothesized that infants would look longer at the impossible event if they: 1) understood that the occluded objects still existed behind the screen, 2) understood that two objects should be left on the stage after the screen rotates down, and 3) were surprised to see only one object. The infants' looking time to each display was measured, and the results showed that the infants did look longer at the impossible event. This suggests that they have the ability to compute the results of simple arithmetical operations. Two classes of models have been proposed to explain why the infants looked longer at the impossible event.

Wynn (1992; 1998) has proposed that infants' arithmetic abilities are due to the existence of an accumulator that is dedicated to representing and reasoning about number. According to Wynn, a pulse generator puts out 'pulses' at a constant rate, and the pulses can be passed into an accumulator by the closing of a switch. When the switch closes for a brief, fixed amount of time an item is "counted". Roughly the same amount is passed into the accumulator for each item counted because the pulses occur at a constant rate. The total number of items in a count is determined by the final accumulation of pulses, and this representation can be compared to another accumulator's content.

Simon (1997) and others (Uller et al., 1999) have proposed that infants look longer at the impossible events because they are able to reason about the existence of the objects behind the occluder. According to this view, infants do not possess an inherent mechanism for number, but instead they have the ability to build a separate representation, or object-file, for each object they see during the test events. The object files are abstract representations that allow the infant to keep track of the occluded objects. For example, for a 1 + 1 = 1 event, the infant would begin with one object file for the first object. Then, a second object file would be opened when the second object is added to the display. The infant has a representation for two objects before the screen rotates down. If there is a mismatch between the number of object files constructed before the screen rotates down and the number of object files constructed after the screen rotates down, longer looking is expected. In this example, the infant will look longer at the 1 + 1 = 1 event because there is a mismatch.

However, both of these models are suspect because certain problems exist with the design of the arithmetic studies (Koechlin et al., 1997; Simon et al., 1995; Uller et al., 1999; Wynn, 1992). One problem is that the infants could be looking longer at the impossible event because they detected a change in the amount of some spatial dimension, and not because they detected a change in number (Feigenson et al., 2000). Feigenson et al. found that when number and spatial dimensions are controlled, infants do not look longer at impossible numerical events. Instead, infants look longer at events that are impossible because of an unexpected change in spatial dimensions.

Feigenson et al. (2000) controlled for an important variable, but some of the infant arithmetic studies, including Feigenson et al., have other problems. Although the events were created to test differential looking between possible and impossible events, possibility and impossibility are confounded with (1) novelty and familiarity and (2) the number of objects on the stage after the screen rotates down. These confounds can affect the results of a study, and studies on object permanence have shown that these confounds need to be addressed (Bogartz & Shinskey, 1998; Bogartz et al., 2000; Bogartz et al., 1997; Cashon & Cohen, 2000; Marks & Cohen, 2000; Meltzoff & Moore, 1998; Rivera et al., 1999; Schilling, 2000). Each of these confounds is explained below.

It is well known that infants can have familiarity or novelty preferences depending on their age, what they see during habituation, and how long they see it (Hunter & Ames, 1988; Hunter, Ross, & Ames, 1982; Rose, Gottfried, Melloy-Carminer, & Bridger, 1982). Bogartz et al. (1997), and others (Bogartz & Shinskey, 1998; Bogartz et al., 2000; Cashon & Cohen, 2000; Rivera et al., 1999; Schilling, 2000), have applied this knowledge and have proposed alternative explanations for a few of the recent violation-of-expectation studies that were conducted (Baillargeon & Devos, 1991; Baillargeon & Graber, 1987; Baillargeon et al., 1985; Kellman & Spelke, 1983). They suggested that the impossibility of the events played no role in the infants' looking times. Instead, the novelty and familiarity relations between the event observed during habituation and the event observed on test trials influenced looking time.

One influential study that used the violation-of-expectation paradigm was the Baillargeon et al. (1985) "drawbridge" experiment. In this experiment, 5-month-old infants were habituated to a screen that moved back and forth in a 180-degree arc. After habituation, a box was placed behind the screen and the infants were shown two test events. In one event, the possible event, the screen stopped rotating when it reached the box. In the second event, the impossible event, the screen rotated the full 180 degrees as if the box were no longer there. Supposing that infants look longer at events that are surprising or unusual, Baillargeon et al. proposed that if the infants understood that the box existed behind the screen, they should look longer at the impossible event. The results revealed that the infants did look longer at the impossible event. Preference for the impossible event suggests that the infants 1) understood that the box continued to exist after it was occluded by the screen, 2) understood that the box was solid, 3) understood that one solid object can not pass through another solid object and, 4) were surprised to see the screen rotate through the location of the box.

As was mentioned above, recent studies have provided an alternative interpretation of the “drawbridge” study (Bogartz et al., 2000; Cashon & Cohen, 2000; Rivera et al., 1999; Schilling, 2000). The infants’ preferential looking can be explained by simple perceptual preferences without the infant having knowledge of occluded objects or impossible events. Bogartz et al. (2000) proposed that the infants could have a screen familiarity preference or a screen novelty preference, and these preferences are confounded in the possible and impossible events in Baillargeon et al. (1985). Infants will prefer to look at a familiar screen rotation when they have not had enough time to process this rotation. On the other hand, infants will look longer at a novel screen rotation if the familiar rotation has been fully processed.

In the first experiment (Bogartz et al., 2000), 5.5-month-old infants were habituated, between infants, to the 180-degree screen rotation, the 180-degree screen rotation with a block placed behind the screen, or the 120-degree screen rotation with a block placed behind the screen. Then the infants were tested, within infants, on these three events and also a forth event, the 120-degree screen rotation. In Baillargeon et al. (1985), the infants were only habituated to the 180-degree screen rotation. In the replication of the Baillargeon et al. study, the results contradicted what Baillargeon et al. found. The infants who were habituated to the 180-degree screen rotation looked longer at the 120-degree rotation with the block placed behind. This is a possible event and also the novel event. After looking at the test data, the infants were separated into novelty preferers and familiarity preferers. The infants with a novelty preference looked longer at the novel event and the infants with a familiarity preference looked longer at the familiar event, regardless of whether the event was possible or impossible. The different looking preferences found in these studies may not be due to the infant possessing knowledge of occluded objects. Instead, it may be that the infants look longer at one of the events depending on how much processing has occurred.

In some of the infant arithmetic studies, the same type of explanation is possible. The impossible event is also the familiar event in the addition and subtraction conditions. At the beginning of each addition condition trial, on the <u>initial event</u>, one object is placed on the stage. Then, after the screen rotates down, on the <u>final event</u>, one object is located on the stage on three trials (1 + 1 = 1) and two objects are located on the stage for the other three trials (1 + 1 = 2). When there is one object on the stage on the final event, the event is both impossible and familiar relative to the initial event. If the infants prefer the familiar event, then longer looking at the arithmetically impossible final event might not be caused by surprise. The infants could be looking longer at the impossible final event because it is also the familiar event. If looking is solely dependent on familiarity, and not whether the final event is impossible or possible, then the conclusions of the infant arithmetic studies are incorrect.

There are two types of familiarity in the Wynn (1992) study: long-term and short-term familiarity. The long-term familiarity effect occurs because by the end of the addition condition, summing over the initial events and final events, an infant has seen one object on the stage nine times and two objects on the stage only three times. Over the course of the experiment the impossible event is confounded with familiarity because it has been seen more often. The short-term familiarity effect occurs within each individual trial. All six trials in the Wynn addition condition began with one object on the stage. When the final event is one object on the stage, the event is not only impossible, but is familiar because it also occurred as the initial event. When the final event is two objects on the stage, the event is possible, but it is also novel because the initial event was different.

The same familiarity confounds exist in Wynn's (1992) subtraction condition. However, in this condition each event begins with two objects on the stage. Then, as the final event, one object is located on the stage on three trials and two objects are located on the stage on three trials. After six trials, infants have seen two objects on the stage nine times and one object on the stage only three times. Once again, impossibility is confounded with long-term familiarity. The long term and short-term familiarity effects in the subtraction condition mirror the effects in the addition condition.

The second confound is more subtle. The impossible events are also confounded with the number of objects on the final event. In the addition condition, the impossible event consists of one object on the final event. In the subtraction condition, the impossible event consists of two objects on the final event. At first glance it seems that this is balanced so that a preference for a certain number of objects can not be an explanation of the results. However, in many of the infant arithmetic studies, the results are much stronger for the subtraction conditions (Koechlin et al., 1997; Wynn, 1992). In fact, in experiment 1 of Wynn's original study (1992), the infants did not look longer at the impossible events in the addition condition, but they did look longer at the impossible events in the subtraction condition. If infants have a preference for looking at more objects, this pattern of results is expected.

Wynn's experiment 3 (1992) provides further evidence for infants possessing a preference for more objects on the final event. Infants were presented with possible (1 + 1 = 2) and impossible (1 + 1 = 3) events. They looked longer at the impossible 1 + 1 = 3 events, but the 1 + 1 = 3 events are confounded with the number of objects on the final event. The infants may have a preference for looking at more objects on the final event, and this may explain the results of experiment 3 and for why the results of the subtraction conditions are stronger.

A recent study supports both the familiarity and the number of objects explanations (Marks & Cohen, 2000). Marks and Cohen replicated Wynn's original experiment, but they also included two additional events in each condition. In the addition condition, the following events were used: 1 + 1 = 0, 1 + 1 =1, 1 + 1 = 2, and

1 + 1 = 3. The events were presented in two blocks. During the first block, infants looked significantly longer at one object. This replicates Wynn's findings, but it also supports the familiarity preference explanation. During the second block, these same infants looked significantly longer at two objects than at one object. The infants also looked longer at three objects than at one object, but the result was not significant. The infants shifted from a preference for the familiar/impossible event to a preference for the more objects events.

The results of the subtraction condition are similar. In the subtraction condition, the following events were used: 2 – 1 = 0, 2 – 1 = 1, 2 – 1 = 2, and 2 – 1 = 3. During the first block, infants looked significantly longer at two objects than at one object. During the second block, there was a significant preference for two or three objects rather than one object. Again, this result replicates Wynn's findings, but a familiarity preference, a preference for more objects on the final event, or both may be involved.

The first part of the present study is a replication of Wynn's addition condition (1992). The impossible event is still confounded with familiarity, and it is reasonable to expect that the infants will look longer at the impossible event as in past studies. However, if the infants prefer two objects over one object on the final event, longer looking to the possible event is expected. The second part of the study includes two new conditions in order to eliminate the confounds. If the Wynn results are due to a familiarity preference, rather than an arithmetic capacity, the infants in this study should look equally at the possible and impossible events when the familiarity confound is eliminated. If the Wynn results are due to a preference for more objects, rather than an arithmetic capacity, the infants in this study should also look equally at the possible and impossible events when the more object confound is eliminated. If the infants have arithmetic abilities, they should look longer at the impossible events rather than at the possible events regardless of the condition.

In infant arithmetic studies (Koechlin et al., 1997; Simon et al., 1995; Uller et al., 1999; Wynn, 1992), there are several variables that may affect infants' looking times. By formulating and testing a regression model that includes additional possible variables' effects on looking time, it may be possible to discover why infants look longer at certain events. Each variable included in the model can have some effect on the overall looking time. Bogartz (unpublished manuscript) proposed that the model

Looking Time (L) = l (constant) + f (initial event, final event) + d (two objects present in final event) + p (possibility relation between initial event, hand event and final event) + h (whether the hand was empty or not) + n (the number of times previous initial events and final events have been the same as the current final event) + tr (trial number) + s (individual subject level) + e (an independent normally distributed error)

could be tested to see which of these variables affects looking time.

The variable f depends on the relation between the initial event shown before the screen rotates up and the final event shown after the screen rotates down. This is the short-term familiarity effect. The variable f will have a positive value if the initial event is the same as the final event and a negative value if the two events are different. The variable d allows for the possibility of a looking preference for two objects on the final event. The variable p is positive if the event is impossible and negative if the event is possible. The variable h represents the effect of how many objects are in the experimenter's hand during the addition or subtraction part of a test trial. It is possible that an empty hand may have a different effect than a hand with an object in it. The variable n represents the long-term familiarity effect. The total number of times the infant has seen one or two objects on the stage on previous trials, including initial events and final events, determines n. The final variables included in the model are the trial effect, tr; the individual's level of looking, s; and the normally distributed errors, e.

The components listed above can be used to analyze the events and the test sequence Wynn (1992) used. According to the events and event sequence, the regression equation can be coded as shown in Table 1, which lists Wynn's events and shows the codings of the independent variables for these events. Bogartz (unpublished manuscript) suggested that a correlation matrix be used to evaluate the relations among the proposed components of looking time. The four components we are most interested in are f, p, d, and n. The correlation matrix in Table 2 shows that short-term

Table 1: Codings for Wynn's (1992) addition events, order 1.

Event	f	d	p	h	n
1 + 1 = 1	1	-1	1	-1	1
1 + 1 = 2	-1	1	-1	-1	0
1 + 1 = 1	1	-1	1	-1	4
1 + 1 = 2	-1	1	-1	-1	1
1 + 1 = 1	1	-1	1	-1	7
1 + 1 = 2	-1	1	-1	-1	2

familiarity, f, and number of objects on the final event, d, are perfectly correlated with possibility/impossibility, p. Also, long-term familiarity, n, and possibility/impossibility and are highly correlated. A preference for familiarity or a preference for one object are possible explanations for Wynn's results since they are confounded with impossibility. Devising events and event sequences that decrease the strength of, or eliminate these relationships allows us to test whether familiarity, impossibility, number of objects, or all three are influencing infants' looking times.

Table 2: Correlation matrix for Wynn (1992).

	f	d	p	h	n
f	1				
d	-1	1			
p	1	-1	1		
h	0	0	0	1	
n	.63*	.63*	.63*	0	1

Note. For order 2, the correlations are .74.*

Table 3 shows the events for Wynn's (1992) addition design and for the two new conditions. Wynn's addition condition, condition 1, consists of four 1 + 1 = 1 events and four 1 + 1 = 2 events. Condition 2 and condition 3 consist of eight different events. Two orders were used in each condition.

Table 3: Events for condition 1 (Wynn, 1992), condition 2, and condition 3.

Trial	Condition 1 Order 1	Condition 1 Order 2	Condition 2 Order 1	Condition 2 Order 2	Condition 3 Order 1	Condition 3 Order 2
1	1 + 1 = 1	1 + 1 = 2	1 + 0 = 1	2 + 1 = 2	1 – 1 = 1	2 + 0 = 2
2	1 + 1 = 2	1 + 1 = 1	1 + 0 = 2	2 – 1 = 1	1 + 1 = 2	2 + 1 = 1
3	1 + 1 = 1	1 + 1 = 2	1 + 1 = 1	1 + 1 = 1	1 + 0 = 1	2 – 1 = 2
4	1 + 1 = 2	1 + 1 = 1	2 + 0 = 1	1 + 1 = 2	2 – 1 = 1	1 + 0 = 2
5	1 + 1 = 1	1 + 1 = 2	2 - 1 = 1	1 + 0 = 1	2 + 1 = 1	1 + 1 = 2
6	1 + 1 = 2	1 + 1 = 1	2 + 0 = 2	1 + 0 = 2	2 – 1 = 2	1 + 0 = 1
7	1 + 1 = 1	1 + 1 = 2	1 + 1 = 2	2 + 0 = 2	1 + 0 = 2	2 – 1 = 1
8	1 + 1 = 2	1 + 1 = 1	2 + 1 = 2	2 + 0 = 1	2 + 0 = 2	1 – 1 = 1

Table 4 shows the codings of the independent variables for the events in condition 2. The correlation matrix in Table 5 shows that there is no correlation between impossibility, p, and short-term familiarity, f; impossibility, p, and long-term familiarity, n; and impossibility, p, and number of objects, d. Half of the trials begin with one object while the other half begin with two objects. Furthermore, half of the

Table 4: Codings of the independent variables for the events in condition 2, order 1.

Event	f	d	p	h	n
1 + 0 = 1	1	-1	-1	1	1
1 + 0 = 2	-1	1	1	1	0
1 + 1 = 1	1	-1	1	-1	4
2 + 0 = 1	-1	-1	1	1	5
2 - 1 = 1	-1	-1	-1	-1	6
2 + 0 = 2	1	1	-1	1	4
1 + 1 = 2	-1	1	-1	-1	5
2 + 1 = 2	1	1	1	-1	7

trials are possible and half of the trials are impossible. According to Wynn's results, the infants should look longer at the impossible events, and if the infants look longer

Table 5: Correlation matrix for the independent variables for the events in condition 2, order 1.

	f	d	p	h	n
f	1				
d	0	1			
p	0	0	1		
h	0	0	0	1	
n	0	0	0	-0.67	1

Note. For order 2, the correlation between h and n is .87.

at the impossible events, it will not be due to the final event being familiar or to the final event consisting of more objects. According to the familiarity hypothesis, the infants should look longer at the familiar events. According to the number of objects hypothesis, the infants should look longer when there are two objects on the final event.

Table 6 shows the codings of the independent variables for the test events in condition 3. The correlation matrix in Table 7 shows that there is no correlation between impossibility, p, and short-term familiarity, f; impossibility, p, and long-term

Table 6: Codings of the independent variables for the events in condition 3, order 1.

Event	f	d	p	h	n
1 - 1 = 1	1	-1	1	-1	1
1 + 1 = 2	-1	1	-1	-1	0
1 + 0 = 1	1	-1	-1	1	4
2 - 1 = 1	-1	-1	-1	-1	5
2 + 1 = 1	-1	-1	1	-1	6
2 - 1 = 2	1	1	1	-1	4
1 + 0 = 2	-1	1	1	1	5
2 + 0 = 2	1	1	-1	1	7

Table 7: Correlation matrix for the independent variables for the events in condition 3, order 1.

	f	d	p	h	n
f	1				
d	0	1			
p	0	0	1		
h	.26	.26	-.26	1	
n	0	0	0	0.46	1

Note. For order 2, the correlation between h and n is -.23.

familiarity, n; and impossibility, p, and number of objects, d. According to Wynn's results, the infants should look longer at the impossible events. However, the familiarity hypothesis predicts that the infants will look longer at the familiar events regardless of whether the event is impossible or possible. The number of objects hypothesis predicts that the infants will look longer when there are two objects on the final event.

CHAPTER II

METHOD

Participants

Fifty-four full term 6-month-old infants from the Amherst, MA area with a mean age of 6 months, 1 day (range: 5 months, 2 days, to 6 months, 17 days) participated in the study. Eight additional participants were excluded from the study because of experimenter error (1 infant), fussiness (5 infants), or disinterest (2 infants). The participants were recruited using state birth records. An invitation letter was sent to the parents and was followed by a telephone call. Participation was voluntary and participants were rewarded with a certificate.

Apparatus

Infants faced a rectangular puppet stage (67 cm high, 70 cm wide, 60 cm deep). The walls and floor were covered with black fabric and a flap was placed on the side and on the back of the apparatus so the experimenter could add objects to the stage. A black curtain occluded the stage between trials. The curtain was attached to a piece of white string which the experimenter used to control the curtain's position. A 60-Watt light bulb was affixed above the center of the stage, out of the infants' sight, to illuminate the stage.

In the center of the stage, on a black box (10 cm high, 23 cm wide, 36 cm deep), a yellow cardboard screen (28 cm by 14 cm by 0.5 cm) was attached to a rod. The rod was connected to a motor that rotated the cardboard screen up and down (90 degrees) so a section of the stage could be occluded. A computer operated the movement of the screen.

The objects used in the study consisted of Grover, Ernie, and Elmo plastic mugs. The characters' faces were on the front of the mug, and a handle was on the back. Each was approximately 8.5 cm tall and between 6.5 and 11 cm in diameter. Grover was colored dark blue, Ernie was colored orange, and Elmo was colored bright red.

Equipment

Each infant was recorded by a video camera placed behind the stage. A second camera, placed behind the infants' right side, recorded the events. A video mixer enabled recording the two camera inputs on one tape. The main image on the monitor was the view of the infant. The view of the events served as a smaller insert in the bottom left corner of the screen. A monitor was placed behind the stage so the first experimenter could watch the infant. Another monitor was placed in a separate room so the second experimenter could code the infants' looking times. A mask on this latter monitor covered the insert, thereby preventing the coder from seeing which event occurred on a given trial.

Two computers were used. Computer 1 was used by the first experimenter to control the rotation of the screen. Computer 2 was used by the second experimenter to code the infants' looking time. Computer 2 also produced audible beeps at the appropriate times during the experiment so that the pacing of the events and trials could be infant-controlled or standardized as needed.

Procedure

The infants sat on their parent's lap facing the stage. The parent was asked to support the infant by the waist, to not interact with the infant, and to close his or her eyes during the trials. The first experimenter was positioned behind the stage, out of the infants' sight. The second experimenter was in a separate room coding the infants' looking times.

Familiarization Trials. In accordance with the procedure of the earlier studies (Koechlin et al., 1997; Simon et al., 1995; Uller et al., 1999; Wynn, 1992), the infants were familiarized before the test trials began. Each familiarization trial began when the curtain was raised. Either one or two objects were on the stage and the trials ended when the infant looked away from the object(s) for 2 continuous seconds. The infants were presented with two of these trials, one trial with one object and the other trial with two objects. The order of presentation was counterbalanced.

Test Trials. For the replication condition, each test trial began with the stage occluded by the lowered curtain. Computer 2 signaled the beginning of the trial. The curtain was raised and the experimenter placed one object on the stage from the infant's left. After the infant looked at the object for 5 seconds, computer 2 beeped. The first experimenter pressed a computer key and the screen, which had been at 0 degrees, pointing toward the infant, rotated up and away from the infant to 90 degrees so the object on the stage was occluded. The screen stayed in an upright position for 5 seconds, allowing the experimenter to introduce a second object from the left side of the apparatus. The experimenter held the object by the handle so that the infant could see the face of the object. This object was placed behind the screen so it was also occluded. Next, the experimenter reached through the back of the apparatus and either created the $1 + 1 = 1$ impossible event by removing one of the objects without the infant seeing it removed, or created the $1 + 1 = 2$ possible event by not removing an object. Although an object was not removed for the possible event, the experimenter still reached through the back of the apparatus and contacted one of the objects so that the motions were the same for both the impossible and possible events. After the event was changed or left unchanged, the screen rotated down to its original position, revealing the object(s), and looking time was measured. Looking time measurements began when the object(s) on the stage were visible to the infant. Test trials ended when the infant looked away for 2 consecutive seconds, after having looked for at least 2 seconds, or when the infant looked for 30 cumulative seconds. Computer 2 then signaled the end of trial and the curtain was closed. The curtain remained closed for each 10-second intertrial interval.

The other two conditions had the same procedure, but the events were slightly different. Both conditions included events that began with two objects on the initial event. Trials with these events began with the experimenter introducing two objects at the same time from the left side of the apparatus. Introducing two objects at the same time was chosen since Wynn's (1992) subtraction events also began this way.

When an object was not added to the initial event (e.g. 1 + 0 = 1), the screen rotated up and the experimenter introduced an empty hand from the left side of the stage. The hand went behind the occluder and then reappeared, still empty, and disappeared at the side of the apparatus as always. At the same time the experimenter's left hand reached through the hole behind the stage and either added or subtracted an object. Then the screen rotated down revealing one or two objects on the stage.

For some trials (e.g. 2 - 1 = 1) an object was taken away after the screen rotated up. The empty hand appeared from the left side of the stage and disappeared behind the screen. The hand reappeared with an object and disappeared at the left side of the apparatus. The infant was able to see the object removed. The screen rotated down revealing one or two objects on the stage, depending on the trial.

The timing of the trials and the looking time criterion for the two new conditions was the same as in the Wynn replication condition.

Measures

The duration of the total looking time to each event was scored. This is the same measure that was used by Wynn (1992).

Design and Analysis

Eighteen infants were randomly assigned to the replication condition and to each of the revised conditions. Within each condition, nine infants were randomly assigned to each order. The looking times between the possible and impossible events were compared in each condition. The regression model was fit to the data in each condition. Various sub-models with p included were tested against the same model with p left out to see if possibility was playing a role in looking time. Various additional analyses were performed to identify which variables were affecting looking time.

CHAPTER III

RESULTS

Interobserver Reliability

A primary observer (CRP) and a secondary observer (JL) scored the looking time on each trial for 24 of 54 infants. A mask, placed over part of the monitor, prevented the observer from seeing which events occurred. A Pearson r of .99 indicated that interobserver agreement was high. The primary observer's judgements were used for data analysis.

Familiarization Trials

Looking times for the familiarization trials were analyzed using a 2 x 3 x 2 mixed model analysis of variance with order (one object first or two objects first) and condition (1, 2, or 3) as between-subjects factors and number of objects on the stage (1 or 2) as the within-subjects factor. No significant differences were revealed. The infants did not look longer at one or two objects during familiarization. The means on the one-object trials and the two-object trials for the three conditions were: $\underline{M}_{1object}$ = 13.26 ($\underline{SD}$ = 9.24), $\underline{M}_{2objects}$ = 12.50 ($\underline{SD}$ = 9.13) for condition 1; $\underline{M}_{1object}$ = 7.39 ($\underline{SD}$ = 4.61), $\underline{M}_{2objects}$ = 8.48 ($\underline{SD}$ = 7.56) for condition 2; and $\underline{M}_{1object}$ = 10.13 ($\underline{SD}$ = 7.36), $\underline{M}_{2objects}$ = 12.26 ($\underline{SD}$ = 10.09) for condition 3.

Test Trials

Condition 1. Infant looking time to the test events can be affected by numerous variables. The model, repeated here, represents an individual infant's looking time by the linear expression

$$Y_{ij} = l + f + d + p + h + n + tr + s_i + e_{ij}.$$

However, the variables f, d, and p are perfectly correlated in condition 1 so it is not possible to discriminate between the effects of the three variables. A 2 x 2 mixed model analysis of variance with order (impossible event first or possible event first) as the between subjects factor and event type (novel/possible/two-objects or familiar/impossible/one-object) as the within subjects factor indicated that the infants looked at the novel/possible/two-objects event ($M = 10.98$, $SD = 7.41$) longer than at the familiar/impossible/one-object event ($M = 8.69$, $SD = 6.37$), $F(1, 16) = 15.11$, $p < .01$. A preference for novelty, possibility, two objects, or a combination of the three could have caused longer looking times.

Condition 2. Analysis of the test trial data from condition 2 was performed using all eight trials. Unlike condition 1, the variables f, d, and p are not correlated in condition 2. By comparing a smaller model, a model without f for example, with the overall model, it is possible to determine whether the excluded variable(s) should be included as determinants of infant looking time. Six smaller models were compared to the overall model.

To test the effect of the possibility/impossibility variable, a smaller model without p was tested against the overall model. The $F(1, 121) = 5.60$ was significant at the .05 level, indicating that the model is better with p included. Surprisingly, the infants looked significantly longer at possible events ($M = 9.57$, $SD = 7.61$) than at impossible events ($M = 7.72$, $SD = 5.57$).

To test the effect of the familiarity/novelty variable, a smaller model without f was tested against the overall model. The $F(1, 121) = 5.51$ was significant at the .05

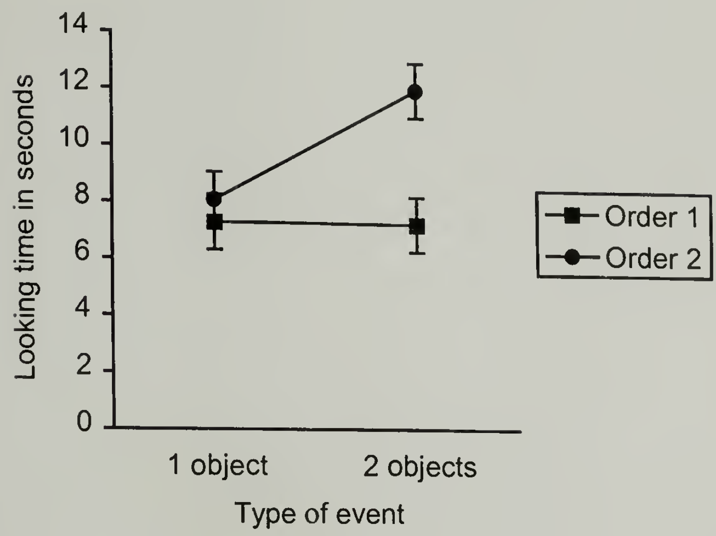
level, indicating that the model is better with f included. The infants preferred the novel events ($\underline{M}$ = 9.46, $\underline{SD}$ = 7.41) over the familiar events ($\underline{M}$ = 7.82, $\underline{SD}$ = 5.87).

To test the effect of the number of objects on the final event variable, a model without d was tested against the overall model. The $\underline{F}(1, 121) = 8.38$ was significant at the .01 level, indicating that the model is better with d included. The infants looked significantly longer at two objects on the final event ($\underline{M}$ = 9.60, $\underline{SD}$ = 7.37) than at one object on the final event ($\underline{M}$ = 7.68, $\underline{SD}$ = 5.88).

The remaining two variables, h and n, were not significant determinants of looking time. A model without h and n was tested against the overall model, and the $\underline{F}(2, 120) = 2.38$ was not significant at the .05 level, indicating that the best model for the data is the model containing f, d, and p. Novelty, two objects on the final event, and possibility increased the infants' looking time.

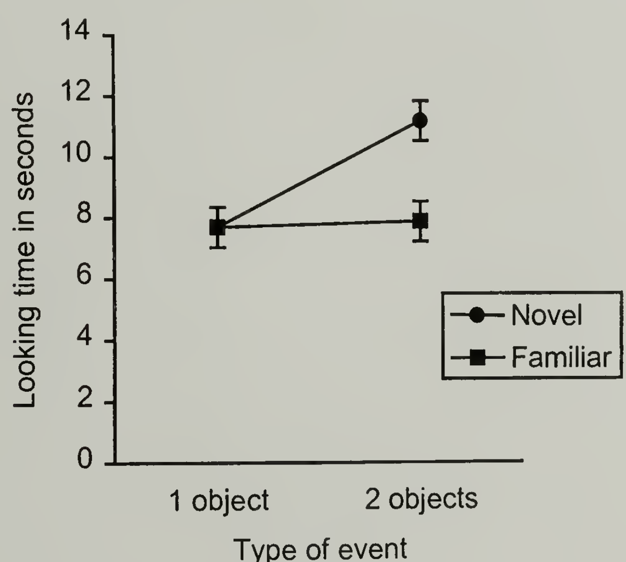
The regression model was not designed to test interaction effects. To test the possibility of interactions between the variables, a 2 x 2 x 2 x 2 mixed model analysis of variance with order (order 1 or order 2) as the between subjects factor and f (familiar or novel), d (one or two objects on the final event), and p (possible or impossible) as the within subjects factors was conducted. The f, d, and p main effects were significant which supports the results of the regression analyses presented above. Also, three significant interactions were revealed. First, an interaction between the number of objects on the final event and order, shown in Figure 1, approached significance, $\underline{F}(1, 16) = 4.12$, $\underline{p} = .06$. The infants in order 2 looked longer at two objects ($\underline{M}$ = 11.98) than at one object ($\underline{M}$ = 8.08), but the infants in order 1 looked equally at two objects ($\underline{M}$ = 7.23) and at one object ($\underline{M}$ = 7.29).

Figure 1: Interaction between the number of objects and order.



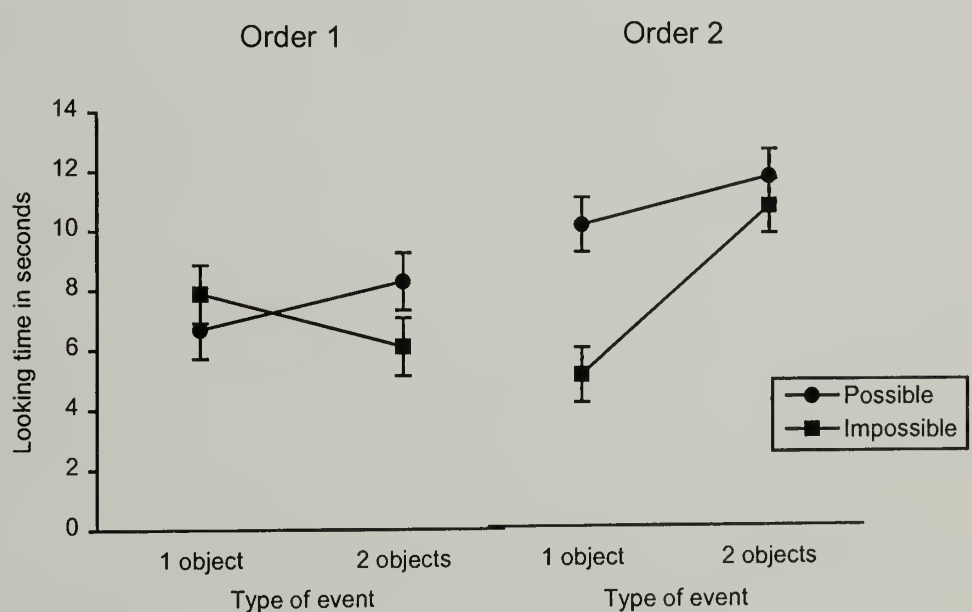
Second, there was a significant interaction between familiarity/novelty and the number of objects on the final event, $\underline{F}(1, 16) = 6.04$, $\underline{p} < .05$. Figure 2 shows the interaction between familiarity/novelty and the number of objects on the final event.

Figure 2: Interaction between familiarity/novelty and number of objects.



The infants looked longer at two objects ($\underline{M}$ = 11.22) than at one object ($\underline{M}$ = 7.7) when the outcome was novel, but they looked equally when the outcome was familiar. Third, there was a significant interaction between impossibility/possibility, the number of objects on the final event, and order, $\underline{F}(1, 16) = 7.76$, $\underline{p} < .05$. Figure 3 shows this interaction. The infants in order 2 looked longer at two objects ($\underline{M}$ = 12.51) than at one object ($\underline{M}$ = 10.76) when the outcome was possible, and they looked longer at two objects ($\underline{M}$ = 11.44) than at one object ($\underline{M}$ = 5.39) when the outcome was impossible. However, this pattern of results was not the same in order 1. The infants in order 1 looked longer at two objects ($\underline{M}$ = 8.33) than at one object ($\underline{M}$ = 6.69) when the outcome was possible, but they looked longer at one object ($\underline{M}$ = 7.89) than at two objects ($\underline{M}$ = 6.13) when the outcome was impossible.

Figure 3: Interaction between impossibility/possibility, the number of objects on the final event, and order.

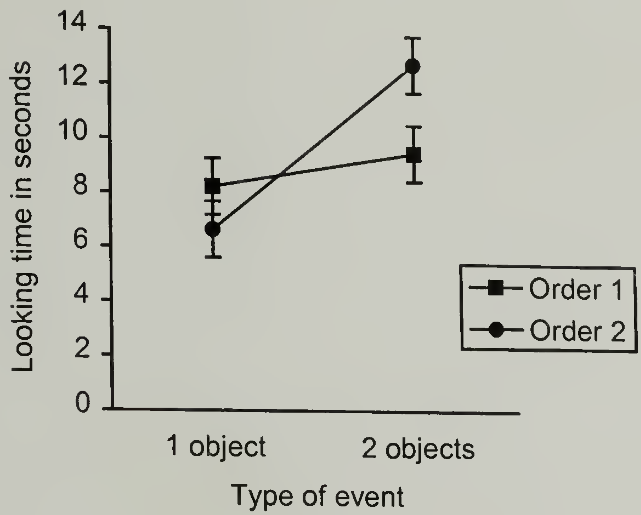


Condition 3. Analysis of the test trial data from condition 3 was performed using all eight trials. To test the effect of the number of objects on the final event variable, a model without d was tested against the overall model. The $F(1, 121) = 15.73$ was significant at the .01 level, indicating that the model is better with d included. The infants looked significantly longer at two objects on the final event ($M = 11.16$, $SD = 7.21$) than at one object on the final event ($M = 7.44$, $SD = 5.37$).

The remaining variables, when left out of the model, did not decrease the strength of the model. A model without f, p, h, and n, was tested against the overall model. The $F(4, 124) = 0.88$ was not significant at the .05 level, indicating that the smaller model does just as well as the larger model in accounting for the data. The number of objects on the final event, d, is the variable affecting looking time. Looking time increases when there are two objects on the final event.

A 2 x 2 x 2 x2 mixed model analysis of variance with order (order 1 or order 2) as the between subjects factor and f (familiar or novel), d (one or two objects on the final event), and p (possible or impossible) as the within subjects factors was used to test the possibility of interaction effects. The d main effect was the only significant main effect, and this supports the regression analysis presented above. Also, a significant interaction between the number of objects on the final event and order was found, $F(1, 16) = 5.51$, $p < .05$. Figure 4 shows this interaction. The infants looked longer at two objects ($M = 9.52$) than at one object ($M = 8.23$) in order 1 and in order 2 ($M_{2\ objects} = 12.80$; $M_{1\ object} = 6.65$), but the difference between their looking at one or two objects was much greater in order 2.

Figure 4: Interaction between the number of objects and order.



CHAPTER IV

DISCUSSION

The results of this experiment may shed some light on the recent infant arithmetic results. First, the replication of the infant arithmetic findings was not successful. The infants looked longer at the possible events than at the impossible events in conditions 1 and 2, and they looked equally at the possible and impossible events in condition 3. The results show that impossibility did not increase infants' looking times. Second, the infants in all three conditions looked longer when there were two objects on the final event than when there was one object on the final event. Third, the infants did not display a familiarity preference, but the infants in the first two conditions did have a preference for novelty. Taken together, the results suggest that the longer looking time to the impossible events in the infant arithmetic studies (Wynn, 1992) may not be due to the infants' possessing mathematical or representational abilities.

Failure to replicate Wynn's original experiment was not a complete surprise for at least two reasons. First, at least one other replication study has also failed (Wakeley et al., in press). Second, Wynn (1992) and Koechlin et al. (1997) found much greater differences in looking time between one and two objects when the subtraction events were used instead of the addition events. Both of these reasons need further explanation.

Wakeley et al. (in press) attempted to replicate Wynn's first two experiments by showing infants addition (1 + 1 = 1 or 2) and subtraction (2 – 1 = 1 or 2) events. The infants' looking times to one or two objects was not different regardless of whether it was an addition or subtraction event. A third experiment involving a different subtraction (3 – 1 = 1 or 2) event was also used, but the looking time to one or two objects was not different.

Wynn (in press) mentioned three differences between the Wakeley et al. procedure and the Wynn (1992) procedure that may have contributed to the different results. First, in Wynn, an experimenter controlled the starting point of each trial so the infant was attentive at the beginning of each trial. Wakeley et al. used a computer program that signaled the beginning of the trial regardless of the infants' behavior. Second, in Wynn, the experimenter could see the infant, but the experimenter in Wakeley et al. could not. The infants' lack of attentiveness to the events might have gone unnoticed in the Wakeley et al. study. Third, Wynn suggests that some of the infants included in the Wakeley et al. study may have been fussy and less attentive because they excluded fewer subjects than Wynn.

None of the criticisms mentioned above can be levied against the procedure in the present study. However, the apparatus used in the present study is not identical to Wynn's apparatus. In the present study, a box, which was covered with black fabric to match the stage and walls, was mounted to the center of the stage to accommodate the occluding screen's motor. Wynn (personal communication, April 24, 2000) suggested that the presence of the box may have distracted the infants in some way. However, if the presence of a box erases infants' mathematical abilities, then the results of the arithmetic studies may be fragile and highly context specific.

The other explanation for the failure to replicate is that results are typically weaker for addition conditions. In the present study addition events were used in the replication condition. Also, the majority of events in the two new conditions were addition events. Some results show that infants will look significantly longer at the impossible event in the subtraction condition but not in the addition condition (Koechlin et al., 1997; Wynn, 1992). Given these results, it is not surprising that the infants did not look longer at the impossible events in the present study, but it is difficult to explain why the infant's looked longer at the possible events in conditions 1 and 2. In condition 1 possibility is confounded with novelty and with two objects on the final event so it is impossible to determine why the infants looked longer. However, in condition 2 these confounds were eliminated and longer looking at the possible events was still found.

If infants do have the ability to add and subtract, why are the results of the infant arithmetic studies so variable? Perhaps it is because young infants' arithmetic competence is fragile, if it exists at all. Feigenson et al. (2000) have presented evidence that supports a non-numerical account for the original findings (Wynn, 1992). They found no evidence that infants are surprised by impossible numerical events. Instead, they found that infants in infant arithmetic studies detect unexpected differences in spatial dimensions. However, Wynn (in press) claims that "the findings reported in Wynn (1992a) are highly robust and consistent". This is a rather bold statement considering that there have been several studies from different laboratories that have failed to replicate the original findings, and have provided alternative explanations for the original findings (Feigenson et al., 2000; Wakeley et al., in press).

The strongest result from the present study was that the infants looked longer when there were two objects on the final event than when there was one object on the final event. This result was found in all three conditions, but only for the second order in conditions 2 and 3. The significant interaction between order and the number of objects on the final event is surprising, but there is a possible explanation. For the first order in conditions 2 and 3, the number of objects on the final event is confounded with trials, and the last three trials consist of two objects on the final event. For the second order in condition 2 there is a mix of one object and two object final events, and for the second order in condition 3 the last three trials consist of one object on the final event. If infants' looking time normally decreases as the number of trials increases, typically because of boredom or fussiness, less looking at the last few events would be predicted. This decrease in looking time over trials may have reduced the amount of looking at the last few events in order 1 that consisted of two objects on the final event.

Even though the results of the present study are not completely clear, preference for a greater number of objects might be the best alternative explanation for the previous infant arithmetic results (Koechlin et al., 1997; Simon et al., 1995; Uller et al., 1999; Wynn, 1992). For the subtraction condition (2 – 1 = 1 or 2) used in experiments 1 and 2, and the addition condition (1 + 1 = 2 or 3) used in experiment 3 of Wynn's study (1992), the impossible event is confounded with the number of objects on the final event. Infants in the subtraction condition looked significantly longer when there were two objects on the final event, the impossible event, when tested with 2 – 1 = 1 or 2 events. Also, infants in experiment 3 looked longer when there were three objects on the final event, the impossible event, when tested with 1 + 1 = 2 or 3 events. Furthermore, the infants in the original addition condition (1 + 1 = 1 or 2) only looked longer when there was one object on the final event, the impossible event, in experiment 2. The infants did not have a preference for the impossible, one object final event in experiment 1.

The infants' longer looking time at the impossible events can be explained by a preference for more objects, and this also explains why infants are less likely to look longer at the impossible events when they are shown the addition events. The impossible event in the addition condition consists of a one object final event while the possible event consists of a two object final event. If infants prefer to look at two objects rather than one object, longer looking at the possible event is predicted. The results of the present study and recent evidence from Marks and Cohen (2000) support this prediction.

The present study and Marks and Cohen (2000) found that infants look longer when there is a greater number of objects on the final event suggesting that infants prefer to look at test events consisting of more objects. By applying these results to the past infant arithmetic studies, it is possible that the results of subtraction events (2 – 1 = 1 or 2) and some addition events (1 + 1 = 2 or 3) may be explained by a preference for looking at more objects rather than a preference for impossible events. If this is true, the existence of infant arithmetic abilities is questionable. Young infants may not possess an inherent mechanism for number as Wynn (1992; 1998) has proposed, and they may not possess the representational abilities necessary to keep track of occluded objects as Simon (1997) and Uller et al. (1999) have proposed.

Infant arithmetic studies are often cited as evidence for object permanence in young infants. If the results of the infant arithmetic studies are due to simple perceptual processing, and not representational abilities, then the claim that young infants have object permanence is called into question. Taken together, the results of the present study and others (Bogartz & Shinskey, 1998; Bogartz et al., 2000; Bogartz et al., 1997; Cashon & Cohen, 2000; Marks & Cohen, 2000; Schilling, 2000) suggest that young infants look longer at events because of simple perceptual explanations, and not because of numerical ability or representational ability. The interpretation of the arithmetic and object permanence studies may be too rich (Haith, 1998). A more plausible interpretation is that infants may not have arithmetic abilities or object permanence, but they may possess preferences for novelty, familiarity, and/or more objects.

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