Cognitive Development, 10, 253–269 (1995)

Do Infants Understand Simple Arithmetic? A Replication of Wynn (1992)

Tony J. Simon
Georgia Institute of Technology

Susan J. Hespos
Philippe Rochat
Emory University

Numerical competence in 5-month-old infants is investigated using a violation-of-expectation paradigm. An experiment is reported which replicates the findings of Wynn (1992). In additional conditions, 5-month-olds are shown to be sensitive to impossible outcomes following addition or subtraction operations on small sets of objects, regardless of identity changes. Results support Wynn's interpretation that infants' responses are based on arithmetical ability. An alternative explanation, that infants' responses are based on their knowledge of the principles of physical object behavior, is also discussed.

INTRODUCTION

A major advance in infancy research is the demonstration that infants are knowers, long before they become sophisticated actors in the environment. Numerous empirical studies provide evidence which undermines the idea that early cognition is strictly dependent on the level of sensorimotor organization achieved by the infant. Before 6 months of age, and prior to the fine tuning of motor skills that will enable the infant to successfully search, reach and manipulate objects in the environment (Rochat, 1989; von Hofsten, 1979), infants appear to process information beyond the immediacy of perception (Mandler, 1988, 1992). By 3 months, infants show a propensity to detect regularities and to anticipate particular outcomes from visual events (Haith, 1993). By 6 months, infants demonstrate long-term memory storage

This research was conducted at the Emory Infant Laboratory, supported by a 1992 Summer Award from Emory University and by Grant No. MH50385-1 from the National Institute of Mental Health, both awarded to Philippe Rochat. The authors wish to express their gratitude to Marie Mize for her help in running the experiments and to all the parents and infants that participated. We would also like to thank David Klahr, Bob Siegler, Dedre Gentner, and Frank Keil for their input early in the development of this research.

Correspondence and requests for reprints should be sent to Tony J. Simon, School of Psychology, Georgia Institute of Technology, Atlanta, GA 30332–0170.

Manuscript received July 7, 1994; revision accepted January 4, 1995

(Ashmead & Perlmutter, 1980; Myers, Clifton, & Clarkson, 1987), recognition (Rovee-Collier & Dufault, 1991), and a capacity to represent objects that are momentarily out of sight (Clifton, Rochat, Litovsky, & Perris, 1991).

Beyond the unveiling of young infants' ability to represent and abstract features of their environment, recent investigations have started to specify further the exact nature of early cognition. In particular, there has been a focus on the question of whether or to what extent infants posses domain-specific biases which aid them in the complex process of acquiring, comprehending and organizing knowledge based on their earliest experiences (e.g., Gelman, 1990; Carey & Gelman, 1991). Thus far, one of the most extensive investigations has concerned the nature of infants' physical knowledge about medium-size objects. This research uses the early propensity to look longer at unfamiliar situations (preferential looking paradigm), testing infants' expectations about the outcome of physical events. In one type of study, infants are habituated to a screen rotating back and forth through 180°. A typical impossible event is one in which a rigid box is placed behind the rotating screen yet fails to impede its movement. In contrast, a possible event would be one in which the screen comes to rest on the hidden box. Results show (e.g., Baillargeon, 1993) that, from 4 months of age, infants tend to look significantly longer at the impossible outcome compared to the possible. These observations suggest that young infants have a basic understanding that objects are substantial, permanent, and occupy space. They conceive physical objects based on a set of basic principles. Using the same basic violation-of-expectation paradigm, numerous studies further demonstrate that, prior to 6 months, infants possess some core physical knowledge (Spelke, 1992). Infants as young as 3 months detect violations of physical principles, including spatial continuity, solidity, and no action at a distance (Baillargeon, 1993; Leslie, 1984; Spelke, 1990).

Aside from physical knowledge, there has also been extensive study of infants' sensitivity to numerical quantity. Studies using habituation methods have shown that infants can reliably distinguish between collections of one to three discrete objects (Antell & Keating, 1983; Strauss & Curtis, 1984; van Loosbroek & Smitsman, 1990). Researchers have also used preferential looking and the violation-of-expectation paradigm to study other aspects of numerical processing in young infants. Starkey, Spelke and Gelman (1990) report that 6- to 8-month-old infants detect numerical correspondences between sets of discrete objects perceived in different sensory modalities. In a series of studies, they habituated infants with successive presentations of either two- or three-object arrays. Except for their number, the nature of these objects and their location on the screen were random. During a series of posthabituation tests, infants were presented with the same number (familiar display), or a different number of objects (novel display). Starkey et al. found that during test trials, infants looked significantly longer at the image corresponding to the novel number. In other studies, Starkey et al. used the auditory-visual preference procedure invented by Spelke (1976). They presented the infant with a pair of visual displays placed side by side, together with a sound track originating from a central location. The sounds corresponded in number to only one of the two visual displays. Starkey et al. report that infants tend to look systematically longer at the display matching the sound track. They conclude that infants as young as 6 months possess early numerical abilities, demonstrating sensitivity to numerosity, an abstract, a-modal property of collections of objects and events (Starkey et al., p. 97).

In a recent study, Wynn (1992) reports observations that she interprets as a demonstration that young infants possess not only the competence for limited numerical abstraction, but also the ability to carry out addition and subtraction operations. Such arithmetical ability, if it exists, would demonstrate that infants are able to operate with concepts of number far beyond the "equivalence and nonequivalence" relations underlying the detection of numerical correspondences reported by Starkey et al. (1990) and by the other habituation experiments. In her study, Wynn (1992) tested 5-month-old infants using a looking-time procedure within the context of the violation-of-expectation paradigm introduced by Baillargeon, Spelke, & Wasserman (1985). Infants were presented with a Mickey Mouse doll resting on a stage. After a few seconds, a screen rotated up occluding the doll and the hand of an experimenter emerged from the side of the stage, adding another doll behind the screen. Following the action, the screen was rotated down revealing either one or two dolls. A possible outcome was classified as one where the result was consistent with the transformations that occurred on the basis of arithmetic (e.g., one object plus another object leaves two objects). An impossible outcome was where the result was not so consistent (e.g., one object plus one object leaves one object).

Possible and impossible outcomes were alternated in successive test trials where the infant's looking time was recorded. In one condition a doll was added (addition) and in another condition there were two dolls on the stage and a doll was retrieved from behind the screen (subtraction). Results show that, in both conditions, infants looked significantly longer at impossible compared to possible outcomes. Wynn interprets these observations as the demonstration that 5-month-olds possess true numerical concepts, having access to "the ordering of and numerical relationships between small numbers" and the ability to "manipulate these concepts in numerically meaningful ways." She concludes: ". . . humans innately possess the capacity to perform simple arithmetical calculations . . ." (Wynn, 1992, p. 750). This interpretation is provocative and requires further empirical scrutiny.

Further investigation is especially necessary because there is a rather unavoidable confound in Wynn's experiment whereby every outcome that is arithmetically incorrect is also physically impossible. Contrary to the principles of object existence that infants are aware of, objects seen placed behind the screen cease to exist in the impossible addition condition, whereas objects that did not previously exist magically appear in the impossible subtraction condition. Given what Spelke, Baillargeon, and others have shown, this alone could be sufficient reason for infants to look longer at such outcomes whether or not they have any understanding of arithmetic. In other words, it seems important to try to distinguish between a surprise reaction arising from mismatched expectations based upon two completely different kinds of knowledge. In one case, the outcome is surprising because the behavior of mentally represented objects behind a screen has not been in accord with the laws of object existence and motion, whereas in the other case the surprise is based on the failure of the objects to conform to the laws of arithmetical transformations. Therefore, our aim in the research presented here is to attempt to distinguish between these two alternative interpretations of the behavior of the infants in Wynn's experiment.

We present an experiment that replicates the observations reported by Wynn (1992). Furthermore, results obtained in additional conditions using the same procedure and paradigm suggest that 5-month-olds are sensitive to impossible outcomes pertaining to the number of objects, *regardless* of identity changes. As a discussion, the interpretation proposed by Wynn is reviewed along with the alternative interpretation that the observed behavior might rather depend on infants' already well-established core physical knowledge about objects.

RATIONALE

We replicated Wynn's (1992) experiment, using a similar procedure and design. In addition, we tested infants in two new conditions:

1. *Impossible identity*—In this new condition, the outcome was arithmetically possible but physically impossible due to the fact that one of the objects changed identity through substitution with another object (identity switch).
2. *Impossible arithmetic and impossible identity*—In this new condition the outcome was both arithmetically and physically impossible. For example, in the case of subtraction, it was arithmetically incorrect because the object that was removed was surreptitiously replaced before the infants were shown the final outcome. (Arithmetically incorrect and identity switch)

These new conditions were designed to assess two alternative interpretations. One interpretation is that infants base their expectation of a particular outcome on an arithmetical computation (as suggested by Wynn). The other is that infants looked longer at a particular outcome because this outcome is recognized to be physically impossible, regardless of arithmetic. Such a response would be consistent with the literature on infants' physical object reasoning (e.g., Baillargeon, 1993). In particular, if infants based their expectations on physical knowledge alone they should not behave differentially in these two conditions. In other words, infants would be equally likely to look longer at outcomes that are physically impossible while arithmetically possible, as to events that are both physically and arithmetically impossible.

METHOD

Participants

A total of 36 infants were tested. Twenty infants (9 boys and 11 girls) were included in the sample used in the final analysis. Eight infants were eliminated due to fussiness, 6 infants due to pretest bias (see subsequent discussion), and 2 infants because they showed a test looking time greater than 2.5 *SD* above the mean. The criteria for selection were identical to the ones used by Wynn (1992). Infants ranged in age from 3 months 22 days to 5 months 19 days (M = 4 months 24 days, SD = 15.62 days). Subjects were healthy, full-term infants born in the Atlanta metropolitan area.

Apparatus

Infants faced a rectangular puppet stage, 67 cm high, 70 cm wide, and 36 cm deep resting on top of a table. The walls and floor of the stage were covered with black fabric. There were flaps cut into the fabric on the side of the stage to allow the experimenter to add or take away objects (The flap was 48 cm tall and 10 cm wide.)

A rod was affixed to the bottom of the stage. At its center was affixed a 53 cm wide by 25.5 high opaque screen made of Styrofoam. The screen could be rotated up or down to reveal or occlude the center portion of the stage. The screen was rotated by the experimenter from behind the stage, using a lever that was connected perpendicularly to the rod. When the screen was raised the surface facing the infant was light gray, which contrasted with the black background. When lowered, the opposite side of the screen was black, which blended with the color of the material covering the lower part of the display. There was a trap door in the back wall of the stage that permitted the experimenter to surreptitiously manipulate the objects when the screen was raised.

The room was lit by two clamp lamps with 60 watt bulbs placed on either side, behind and 1 m above the infant. The display was illuminated by a halogen lamp clamped to the top of the stage. The stage lamp was concealed from the infant's view by a black curtain hanging from the ceiling. Both the room and the stage lighting were controlled by a dimmer switch accessible to the experimenter from behind the stage. There was a blackout between trials.

Two cameras provided video recording of the testing sessions, one was placed behind the stage, and the other was placed above and behind the infant. The lens of the camera behind the stage was placed against a hole (5 cm in diameter) in the black backdrop at the infant's eye height. When the screen was lowered, this camera provided a view of the infants' face while they were looking at the display. The other camera provided a view of the object on stage as seen from the infant's point of view. Images from both cameras appeared on either side of a split-screen (Pelco model US100DT). In addition, a digital clock (Video Timer VTG22) was superimposed on the image. The split-screen image was both recorded and monitored on-line on a small TV monitor behind the stage, permitting the experimenter to observe the infant throughout testing and to monitor when the infant looked away from the display for longer than two seconds (see procedure that follows). The objects presented to the infant were "Ernie" and "Elmo" characters from the Children's Television Workshop, Sesame Street™ program. These objects were colorful, hard plastic 10.5 × 8 × 15.5 cm dolls available from Illco Jim Henson Productions Inc.

Procedure

During the experiment, the infant sat on the parent's lap facing the stage. The parent was asked not to interact with the infant, holding him or her gently by the hips. Infants were tested in three successive phases. This first phase consisted of five pretest trials. A trial began when the lights were turned on revealing one of five displays on the stage. Each trial lasted until the infant looked away from the display for 2 continuous s (See *Scoring* for operational definition of first gaze). Looking away was assessed from an on-line video on a small TV visible to the experimenter only. The trial terminated when the lights were turned off. During intertrial blackouts the objects were changed for the next trial. Each of the five displays was presented once, consisting of Ernie alone, Elmo alone, two Ernies, two Elmos, and one Ernie and one Elmo). Order of presentation was counterbalanced across participants.

The second phase of testing consisted of familiarization trials. During this phase, infants were presented with six successive trials in which there was an empty stage, then the screen rotated up, the experimenter's hand reached behind the screen, came out empty, and the screen rotated down. These six familiarization trials were designed to acquaint the infant with the occlusion event and the experimenter's hand motion, without any objects involved.

The third phase presented the actual test trials. Infants were presented with objects being placed behind or removed from behind the screen. Infants were randomly assigned to an addition *or* subtraction condition. All the infants were presented with six test trials alternating between possible and impossible outcomes (three of each). The presentation of a possible or impossible event shown on the first trial was counterbalanced across subjects. In the addition condition (see Figure 1a), a trial started when the lights were turned on revealing a single object on stage, either one Ernie or one Elmo. The number of presentations starting with either one Ernie or one Elmo was counterbalanced and equal across participants.

The experimenter waited until the infant looked at the display for 5 s continuously. Then the screen rotated up occluding the object from the infant's view. At this point, the experimenter's hand emerged from the top of the flap located on the left side of the stage holding one of the objects. Special care was taken in handling the object to insure that the identity of the object was not concealed by the experimenter's hand. The object was held by the bottom. The experimenter wiggled the object until the infant attended to it and slowly lowered the object down behind the screen and left empty-handed (5 s). Immediately following, the screen was rotated down revealing either a possible or impossible outcome. The dependent measure was first gaze duration and it was measured from the moment the screen was lowered until the infant looked away for 2 s consecutively. In the possible outcomes following addition, infants were presented with the two logically appropriate objects. There were three different possible outcomes: Elmo + Elmo = 2 Elmos, Ernie + Ernie = 2 Ernies, Elmo + Ernie = Elmo and Ernie. In the impossible outcomes following addition, infants were presented with one of three impossible outcomes. The three different impossible outcomes were: Elmo + Elmo = Elmo (impossible arithmetic), Elmo + Elmo = Elmo and Ernie (impossible identity), Elmo + Elmo = Ernie (impossible arithmetic and identity). The number of appearances and position of characters was counterbalanced within and between participants.

In the subtraction condition (see Figure 1b) the trial began when the lights were turned on revealing two objects on stage, either two Elmos, two Ernies, or one Ernie and one Elmo. The number of presentations starting with these displays was counterbalanced and equal across participants.

The experimenter waited until the infant looked at the display for 5 s continuously. Then the screen rotated up and occluded the object from the infant's view. At this point, the experimenter's hand emerged from the flap located on the left side of the stage and waved to show that it was empty. Then, the experimenter reached behind the screen, and took an object. The object was slowly lifted and wiggled for 5 s above the screen before the experimenter removed it from the stage through the flap. Again, special care was taken in handling the object to insure that the identity of the object was not concealed by the experimenter's hand. Immediately after this the screen was rotated down revealing either a possible or impossible outcome. The

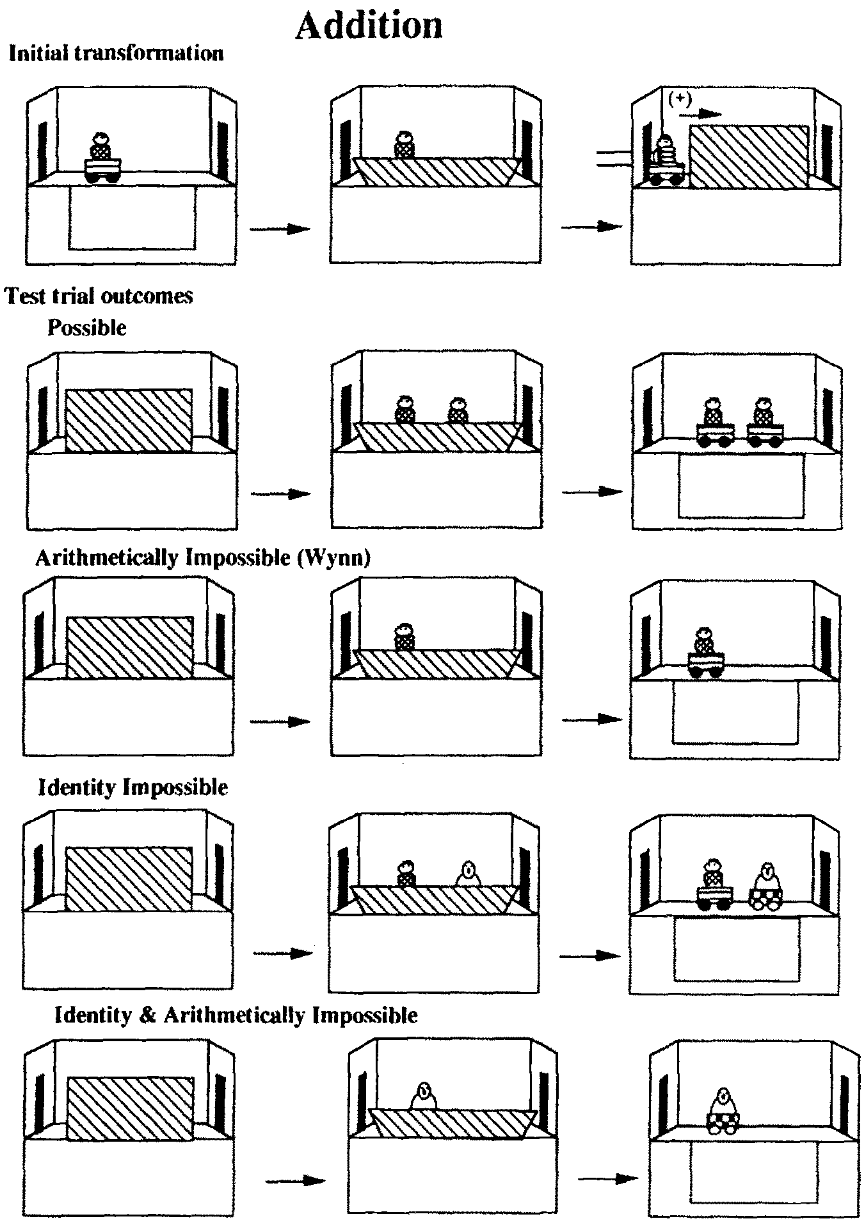

Figure 1a. Sequence of events for the "1 + 1" situation.

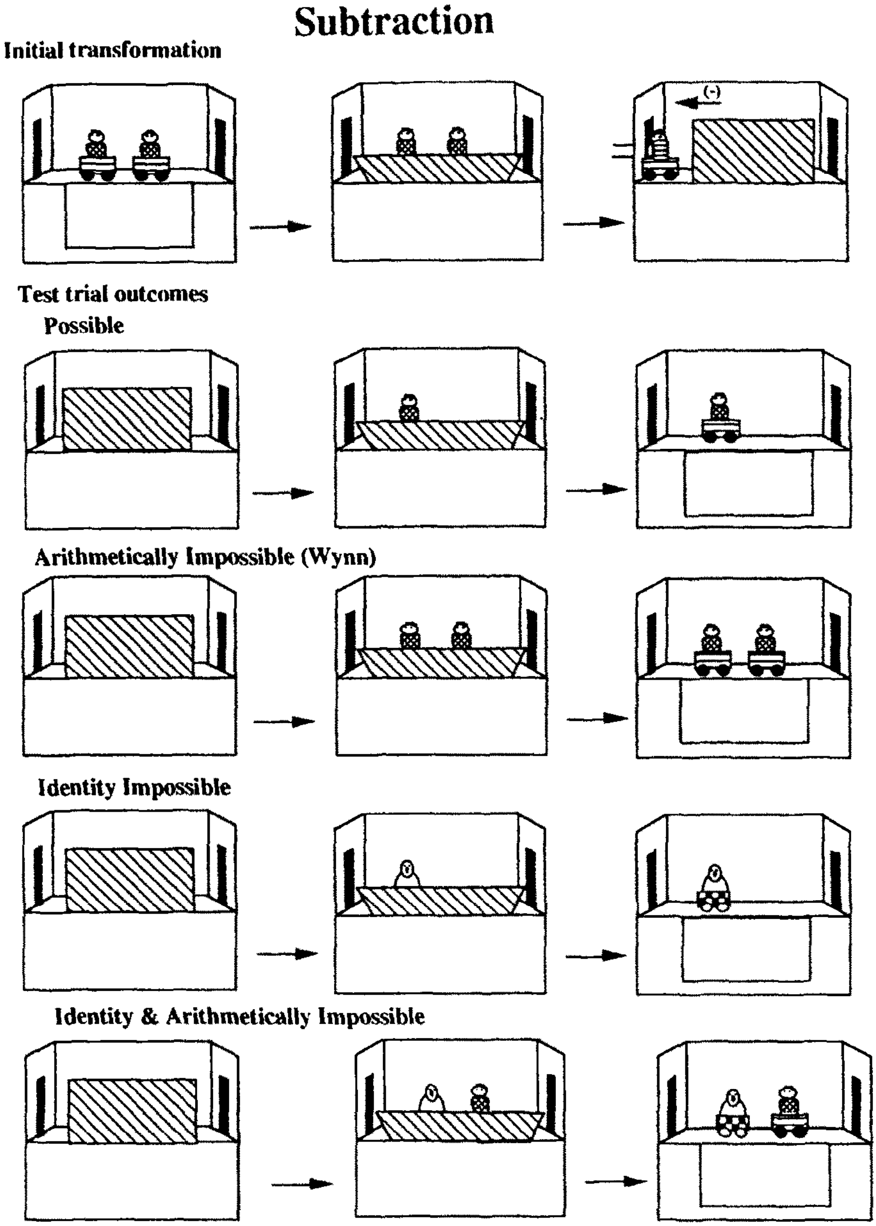

Figure 1b. Sequence of events for the "2 – 1" situation.

dependent measure was first gaze duration and it was measured from the moment the screen was lowered until the infant looked away for 2 s consecutively. In the possible outcomes following subtraction, infants were presented with the logically appropriate object. There were three different possible outcomes: 2 Elmos − Elmo = Elmo, 2 Ernies − Ernie = Ernie, Elmo and Ernie − Elmo = Ernie. In the impossible outcomes following subtraction, infants were presented with one of three impossible outcomes. In the experiment, the appearance and position of characters was counterbalanced and equal within and between subjects. The three different impossible outcomes were 2 Elmos − Elmo = 2 Elmos (impossible arithmetic), 2 Elmos − Elmo = Ernie (impossible identity), 2 Elmos − Elmo = Elmo and Ernie (impossible arithmetic and identity). Again, the number of appearances and position of characters was counterbalanced within and between participants.

Scoring

Two independent coders analyzed the video recording of infants' gaze during pretest (baseline preference) and test trials following either addition or subtraction transformations. Coding was based on an on-line viewing procedure. While viewing the videotape, two independent coders recorded an infant's looking at the display by pressing a button which activated one channel of a computerized event recorder. Coders were blind to what display the infant was looking at and whether she or he was looking at a possible or impossible outcome. An opaque sheet covered the portion of the split image on the TV monitor depicting the event on stage. Based on this coding, first gaze duration was measured from the moment the lights came on (pretest trials) or the moment the screen was lowered revealing the particular display (test trials). First gaze was operationally defined as the first look at the display that was longer than 1 s with no interruption longer than 2 s (see Wynn, 1992). Intercoder reliability was assessed on one third of the total N of pretest and test trials included in the analysis. Average percent agreement between coders regarding first gaze duration was greater than .95.

RESULTS

Pretest

Analysis of first gaze duration showed that there was no significant looking preference for any of the five displays. A one-way analysis of variance with repeated measures yielded no significant effect of display, $F(4, 19) = 0.198$, $p = .94$. Furthermore, orthogonal planned comparisons showed that there was no significant effect of one versus two objects on display, $F(1, 19) = 0.240, p = .63$, nor any significant looking bias towards Ernie or Elmo, $F(1,$

19) = 0.31, p = .58. The individual mean first gaze duration scores were as follows: Elmo—11.54 seconds, Ernie—11.65 seconds, Elmo and Ernie—12.01 seconds, two Ernies—12.75 seconds, two Elmos—11.55 seconds.

Replication of Wynn (1992)

Conditions replicating Wynn's experiment were analyzed separately. In general, our results confirmed Wynn's findings. The dependent measure was first gaze duration. In both addition and subtraction conditions, infants tended to look longer at the incorrect arithmetic outcomes compared to the possible outcomes (see Figure 2). An analysis of variance with one between-subject variable of condition 2 (addition or subtraction) X a within-subject variable of outcome 2 (one object or two object) yielded a significant condition-by-outcome interaction $F(1, 18) = 5.78, p < .03$. In the addition condition (1 + 1), there was, on average, a longer first gaze duration for the one-object test outcome (M = 11.25, SD = 8.47) in comparison to two objects (M = 8.21, SD = 4.93). In the subtraction condition (2 = 1), there was, on average, a longer first gaze duration for the two-object test outcome (M = 10.76, SD = 5.98) in comparison to one object (M = 6.77, SD = 4.24).

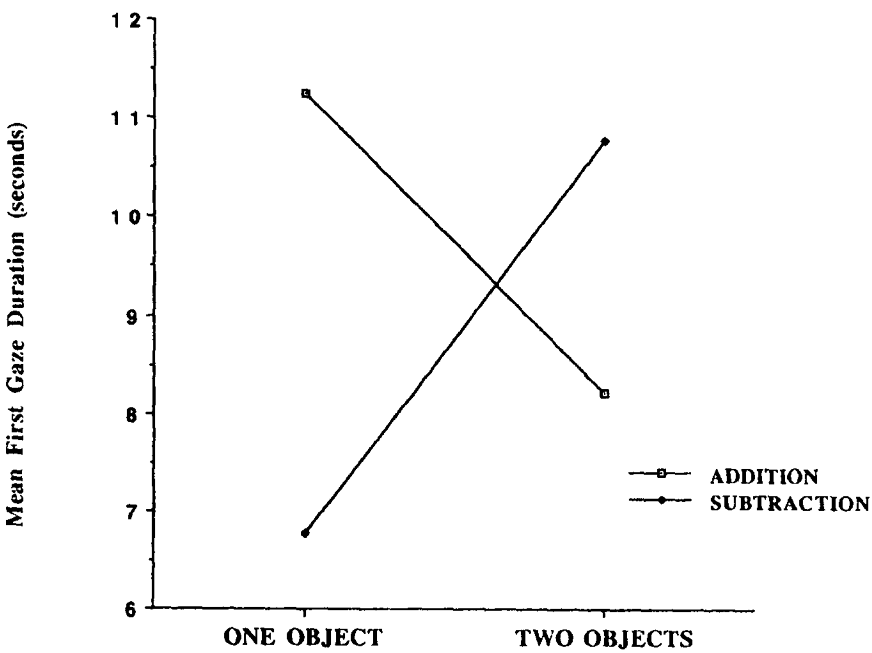

Figure 2. Mean first gaze durations for 1 and 2 objects.

Global Analysis

The analysis pertaining to all conditions indicated that infants, in general, tended to look longer at the incorrect arithmetic outcome, *regardless* of any violation of object identity. An analysis of variance on the first gaze duration during test trials was performed. There was a between-subject variable of condition 2 (addition or subtraction) X the within-subject variables 2 outcome (possible or impossible) X 3 type (impossible identity, impossible arithmetic, impossible identity and arithmetic). The ANOVA yielded a marginally significant main effect of outcome, $F(1, 18) = 4.09, p < .06$ and no other significant main effects or interactions. Since there was no main effect of condition, the addition and subtraction data were collapsed in further analyses. Figure 3 shows the mean first gaze duration across types of outcomes: possible (8.11 seconds), impossible arithmetic (11.01 seconds), impossible identity (8.33 seconds), impossible identity and arithmetic (10.72 seconds). Of the impossible events, those with impossible arithmetical outcomes produced long looking times. In contrast, the mean first gaze duration for the impossible identity condition was comparatively short. A planned comparison showed that the means for this condition were not significantly different from those of the possible events, $F(1, 18) = .029, p > .86$. A further orthogonal planned comparison between the identity impossible outcome and the two other types of impossible outcomes (incorrect arithmetic and

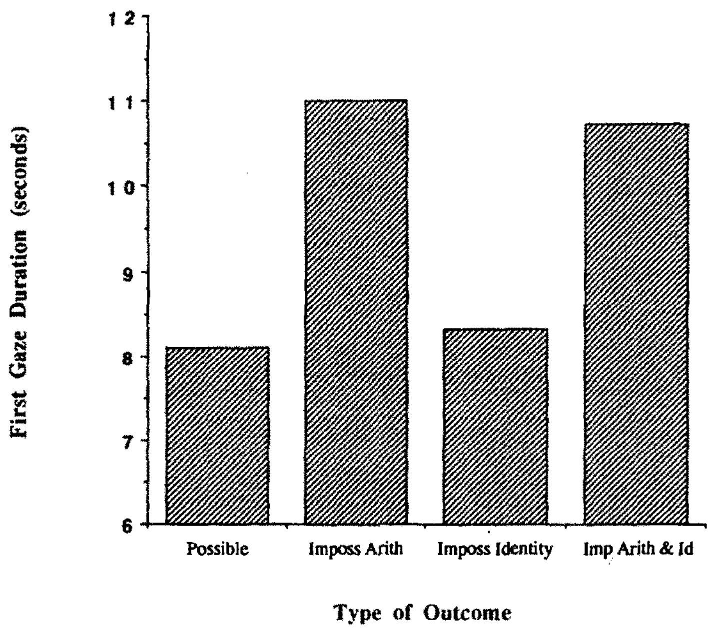

Figure 3. Comparison of mean first gaze durations for different outcome types.

incorrect arithmetic-impossible identity outcomes) collapsed together yielded a significant contrast, $F(1, 18) = 4.687, p < .05$. Lastly, conditions with arithmetically impossible outcomes produced longer looking times than conditions producing arithmetically possible outcomes, regardless of identity, $F(1, 18) = 9.781, p < .01$.

Control Experiment

Since changes in identity apparently were not perceived by infants to be impossible outcomes, it is critical that we know whether infants can distinguish the objects used in our experiment from one another. Therefore, a control was performed to assess infants' discrimination between the Ernie and Elmo dolls used in the experimental situation. Ten infants were included in this control with a mean age of 5 months 1 day. As in the experimental situation, infants were seated on their parent's lap in front on the same puppet stage, using the same basic procedure. In five familiarization trials, infants were presented with either Elmo or Ernie alone. Each familiarization trial lasted until the infant looked away from the display for 2 consecutive s, as in the main experiment.

Following familiarization, infants were presented with six test trials with alternated presentations of either Ernie or Elmo alone. Each test trial lasted 20 seconds. Time spent looking at the object was recorded. Five of the infants were familiarized with Ernie, 5 with Elmo. The first test trial was always the novel doll. Overall, infants looked longer at the novel doll compared to the familiar one. An ANOVA with 2 within-subject factors (Novelty X Order) pertaining to first gaze duration yielded a significant novelty effect $F(1, 9) = 14.59, p < .01$ and no significant main effect of test Order, nor any significant Novelty X Order interaction. Although these results do not rule out all possible interpretations they do indicate that the tested 5-month-olds are able to discriminate between Ernie and Elmo, the two experimental objects.

DISCUSSION

As shown in this article, we were able to replicate the behavior of the infants in Wynn's study. Infants looked longer at what Wynn called arithmetically incorrect outcomes. This result is consistent with Wynn's view that the children interpreted the outcomes based on arithmetical knowledge. We also created a condition where the outcomes were physically impossible but which could be interpreted as arithmetically correct. In our "impossible identity" condition Elmo turned into Ernie (or vice versa) while behind the screen during an otherwise normal addition or subtraction trial. Because the laws of physical object behavior dictate that this should not happen, we expected infants would look longer at such outcomes if their reactions were based on physical object reasoning. Yet, as reported earlier, our subjects showed no increase in looking time in response to such outcomes. This result, then, is also consistent with Wynn's interpretation that only arithmetically impossible outcomes are surprising to 5-month-old infants.

This experiment demonstrated that, when infants were presented with scenes where objects underwent various transformations, those that violated laws of object existence and simple arithmetic produced increased looking time, whereas those where existence outcomes alone were impossible did not. Increases in looking time are generally interpreted as showing that the infants have some accessible representation of what the correct outcome should have been and that their increased attention is an indication that they have detected an unexpected outcome. Wynn (1992) concluded that such a response to conditions like those in her experiment and ours suggests the existence of arithmetical knowledge in 5-month-old infants. We have provided evidence in support of that view here. We did not provide evidence for an alternative interpretation; that the observed behavior was based on physical and not arithmetical reasoning.

However, the alternative interpretation still cannot be completely ruled out. Very recent research by Xu (1993) has suggested that, under some circumstances, infants ignore the identity of objects as they track their existence and whereabouts and attend only to the object's spatiotemporal characteristics. In other words, in a "where" task the "what" of the object appears not to matter much. Thus, infants in our impossible identity condition may not have been surprised by Ernie turning into Elmo because they did not notice that such a transformation had taken place.

This interpretation is consistent with the findings of Xu (1993) who directly investigated the encoding and representation of object identity by 10-month-old infants. In her first experiment, Xu presented 10-month-old infants with objects in two conditions where two screens were separated by an open space. In the *discontinuous* condition, infants were habituated to an object appearing to the right of the right screen and returning behind it, followed by an identical object moving to the left of the left screen, and then returning. In the *continuous* condition a single object moves to the right, then visibly between the screens and then to the left. As predicted, infants were surprised by an outcome where two identical objects, one behind each screen, were revealed in the continuous condition, and where a single object was revealed behind one screen in the discontinuous condition. This was taken as evidence that 10-month-olds use spatiotemporal information to track the identity and existence of objects.

In the second experiment, the same movements were made by objects but behind a single, longer screen with no intervening space. In the *different* condition, a toy duck moved out from behind the screen and returned on one side followed a short time later by a ball moving out from behind the same screen and returning on the other side. In the *same* condition, an identical object appeared and returned, first from one side of the screen and then the other. As predicted, the infants showed surprise when two objects were revealed in the test phase of the *same* condition. However, despite evidence that they could tell the objects apart, infants also showed surprise when the 2 different objects where revealed in the test phase of the *different* condition, instead of when a single object was revealed. In other words, despite the fact that they would have to interpret it as a single object spontaneously switching identities from a duck to a ball, infants accepted the single object outcome since it was consistent with the spatiotemporal information.

Xu's experiment shows that 10-month-olds will *ignore the identity* of an object when reasoning about its existence while hidden behind a screen. This is exactly the situation that occurred in our impossible identity-correct arithmetic condition. An Elmo character appeared on the stage, then the screen occluded it. Next, a further Elmo character was moved behind the screen. Neither reappeared before the screen was removed so the spatiotemporal information predicted two objects still behind the screen. The fact that the identity of one Elmo changed into an Ernie while hidden did not surprise our subjects at all, even though the objects could be distinguished from one another. This is, we believe, because the spatiotemporal information in the situation specified that there would be *some object, some other object (and only those)* behind the screen. Just like Xu's older infants, the change in identity was accepted and not treated as an impossible outcome by our subjects. Put another way, if a duck could also be a ball in Xu's experiment, then an Elmo could also be an Ernie in ours when these situations were consistent with spatiotemporal information. So our subjects' failure to look longer at what we called an impossible identity-correct arithmetic situation is actually consistent *both* with the interpretation that infants' surprise reactions were based on violations of physical object knowledge, and with the view that the children's surprise reactions were based on arithmetical knowledge.

Thus, this study has replicated two important recent results. First, when presented with situations that are arithmetically incorrect, 5-month-old infants show surprise reactions and look longer than at arithmetically and physically consistent outcomes. Second, when tracking the existence of an object that was seen to move behind a screen, infants will ignore changes in the object's identity and attend instead to its spatiotemporal specification. This effect was demonstrated in 5-month-old infants just as in Xu's (1993) 10-month-old subjects.

Solving the puzzle of exactly what knowledge the children's behavior was based on will not be easy. A direct empirical test would seem to be impossible to create. In the current experiment this would have required a condition producing a physically possible outcome that was arithmetically impossible. However, one object cannot be added to another object without the result being two objects. Yet, rather than viewing this problem as a confound between number and physical existence, it should probably be recognized as indicating a critical link. Flegg (1983) states that "[t]here is nothing in the physical world that is two. . . . Numbers are idealizations in the mind of particular experiences encountered in the world" (p. 3). Thus, numbers are labels for, among other things, collections of objects and arithmetic is a language for the results of interactions between those objects. Therefore, any understanding of numerical or arithmetical concepts ought to be intimately bound up with an understanding of physical objects and the conditions of their existence. Finding out what young children know about each domain, when they know it and how these sets of knowledge interact is a complex undertaking. Indeed it has been a focus of psychological investigation for a very long time. It is our belief that the recent extension of this investigation into the world of the infant, although difficult, will ultimately reveal a great deal about the beginnings of numerical understanding in the human being.

REFERENCES

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

Ashmead, D.H., & Perlmutter, M. (1980). Infant memory in everyday life. In M. Perlmutter (Ed.), *New directions for child development: Children's memory* (Vol. 10, pp. 126–142). San Francisco: Jossey-Bass.

Baillargeon, R. (1993). The object concept revisited: New directions in the investigation of infants' physical knowledge. In C.E. Granrud (Ed.), *Visual perception and cognition in infancy* (pp. 265–316). Hillsdale, NJ: Erlbaum.

Baillargeon, R., Spelke, E.S., & Wasserman, S. (1985). Object permanence in five-month-old infants. *Cognition, 20*, 191–208.

Carey, S. (1991). Knowledge acquisition: Enrichment or conceptual change? In S. Carey, & R. Gelman (Eds.), *The epigenesis of mind*. Hillsdale, NJ: Erlbaum.

Carey, S., & Gelman, R. (Eds.). (1991). *The epigenesis of mind*. Hillsdale, NJ: Erlbaum.

Clifton, R., Rochat, P., Litovsky, R., & Perris, E. (1991). Object representation guides infants' reaching in the dark. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 323–329.

Flegg, G. (1983). *Numbers: Their history and meaning*. New York: Schoken Books.

Gelman, R. (Ed.). (1990). Special issue on structural constraints on cognitive development. *Cognitive Science, 14*, 3–9.

Gelman, R. (1991). Epigenetic foundations of knowledge structures: Initial and transcendent structures. In S. Carey & R. Gelman (Eds.), *Epigenesis of mind: Studies in biology and cognition* (pp. 293–322). Hillsdale, NJ: Erlbaum.

Haith, M.M. (1993). Future-oriented processes in infancy: The case of visual expectations. In C.E. Granrud (Ed.), *Visual perception and cognition in infancy* (pp. 235–264). Hillsdale, NJ: Erlbaum.

Leslie, A. (1984). Spatiotemporal continuity and the perception of causality in infants. *Perception, 13*, 287–305.

Mandler, J.M. (1988). How to build a baby: On the development of an accessible representational system. *Cognitive Development, 3*, 113–136.
Mandler, J.M. (1992). How to build a baby: II. Conceptual primitives. *Psychological Review, 99*, 587–604.
Myers, N.A., Clifton, R.K., & Clarkson, M.G. (1987). When they were very young: Almost-threes remember two years ago. *Infant Behavior & Development, 10*, 123–132.
Rochat, P. (1989). Object manipulation and exploration in 2- to 5-month-old infants. *Developmental Psychology, 25*, 871–884.
Rovee-Collier, C., & Dufault, D. (1991). Multiple contexts and memory retrieval at 3 months. *Developmental Psychobiology, 24*, 29–56.
Spelke, E.S. (1976). Infants' intermodal perception of events. *Cognitive Psychology, 8*, 53–60.
Spelke, E.S. (1990). Principles of object perception. *Cognitive Science, 14*, 29–56.
Spelke, E.S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review, 99*, 605–632.
Starkey, P., Spelke, E.S., & Gelman, R. (1990). Numerical abstraction by human infants. *Cognition, 36*, 97–128.
Strauss, M.S., & Curtis, L.E. (1984). Development of numerical concepts in infancy. In C. Sophian (Ed.), *The origin of cognitive skills*. Hillsdale, NJ: Erlbaum.
van Loosbroek, E., & Smitsman, A.D. (1990). Visual perception of numerosity in infancy. *Developmental Psychology, 26*, 916–922.
von Hofsten, C. (1979). Development of visually guided reaching: The approach phase. *Journal of Human Movement Studies, 5*, 160–178.
Wynn, K. (1992). Addition and subtraction by human infants. *Nature, 358*, 749–750.
Xu, F. (1993, March). *The concept of object identity*. Paper presented at the biennial meeting of the Society for Research in Child Development, New Orleans, LA.