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Object individuation: infants' use of shape, size, pattern, and color

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Abstract

Recent research indicates that when an event-monitoring paradigm is used, infants as young as 4.5 months of age demonstrate the ability to use featural information to individuate objects involved in occlusion events (Wilcox & Baillargeon, 1998a, Object individuation in infancy: The use of featural information in reasoning about occlusion events. Cognitive Psychology 37, 97–155; Wilcox & Baillargeon, 1998b, Object individuation in young infants: Further evidence with an event monitoring task. Developmental Science 1, 127–142). For example, in one experiment (Wilcox & Baillargeon, 1998b, Object individuation in young infants: Further evidence with an event monitoring task. Developmental Science 1, 127–142) 4.5-month-old infants saw a test event in which a green ball with colored dots disappeared behind one edge of a narrow or wide screen, and a red box with silver thumbtacks appeared at the other edge; the narrow screen was too narrow to hide both objects simultaneously, whereas the wide screen was sufficiently wide to hide both objects at the same time. The infants looked reliably longer at the narrow- than at the wide-screen test event. These and control results suggested that the infants had: (a) used the featural differences between the ball and box to conclude that two objects were involved in the event; (b) judged that both objects could fit simultaneously behind the wide but not the narrow screen; and hence (c) were surprised by the narrow-screen event. The present experiments build on these initial findings by investigating the features to which infants are most sensitive. Four experiments were conducted with infants 4.5–11.5 months of age using the same procedure, except that only one feature was manipulated at a time: shape, size, pattern, or color. The results indicated that 4.5-month-olds use both shape and size features to individuate objects involved in occlusion events. However, it is not until 7.5 months that infants use pattern, and 11.5 months that infants use color, to reason about object identity. It is suggested that these

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results reflect biases in the kind of information that infants attend to when reasoning about occlusion events. Possible sources of bias are discussed.

Keywords: Infants; Occlusion events; Object individuation

1. Object individuation: infants' use of shape, size, color, and pattern

As infants look around them, they routinely observe occlusion events; for example, a box of cereal protrudes from the top of a grocery bag, a ball rolls behind a chair, or keys are dropped into a briefcase. Traditionally, investigators assumed that infants possess very little knowledge about occlusion events (Piaget, 1954). This conclusion was based primarily on results obtained with object manipulation measures, such as search tasks, in which infants younger than about 8 months of age typically fail (see Sophian, 1984; Bremner, 1985; Harris, 1987; for reviews). With the advent of more sensitive visual-attention measures, however, researchers have come to realize that even very young infants reason about occluded objects, and can accurately predict the outcome of occlusion events (Spelke, Breinlinger, Macomber & Jacobson, 1992; Wilcox, Nadel & Rosser, 1996; Baillargeon, 1998; Aguiar & Baillargeon, 1999). These findings have raised questions about the nature of young infants' event representations, and how these representations change over time.

A great deal of research has now been conducted on how infants build representations of one particular kind of occlusion event – events in which objects become fully occluded as they move back and forth behind a screen. Interpreting events in which object move successively in and out of view presents infants with the problem of *object individuation*: determining how many distinct objects are involved in the event. The problem of individuation has recently attracted a great deal of attention from infant researchers. Most investigations have focused on the type of information that infants use to individuate objects (Spelke, Kestenbaum, Simons & Wein, 1995; Xu & Carey, 1996; Wilcox & Baillargeon, 1998a,b) and how this might differ from adults.

Researchers have suggested that adults draw on several types of information when segregating partly occluded objects (Spelke, 1982; Kellman & Spelke, 1983; Needham, Baillargeon & Kaufman, 1997) and that the same types of information can be used to individuate objects in occlusion events (Wilcox & Baillargeon, 1998a). One type of information that adults use is *featural*, such as the shape, size, pattern, or color of an object. When the objects seen to each side of an occluder share the same features, adults assume that they constitute the same individual. For example, if a green ball disappears behind one edge of an occluder and, after a brief interval, appears at the other edge, adults conclude that one ball is involved in the event. In contrast, when the objects seen to each side of an occluder differ in their featural components, adults assume that two separate and distinct individuals are present.

For example, if a green ball disappears behind one edge of an occluder and a red ball appears at the other edge, adults conclude that two balls are involved in the event. Another type of information is *physical*. Adults possess knowledge about the physical properties of objects, including how they should move and interact, that can be used to interpret occlusion events. Consider an event in which the green ball disappears behind one edge of an occluder and then immediately appears at the opposite edge. Adults use the discontinuity in speed to conclude that two balls are involved in the event, one that disappears behind one edge of the occluder and a second identical ball that immediately appears at the other edge. A third type of information is *experiential*. Knowledge about certain objects, or categories of objects, can also be used to helped individuate objects involved in occlusion events. Consider the green ball-red ball event described above, except imagine that prior to the event adults are told that: (a) the green ball changes color when heat is applied; and (b) the occluder is an electric warmer. Given this information, adults would conclude that just one ball is involved in the event; a green ball that turns red when behind the occluder.

2. Object individuation: infants' use of featural information

The focus of current research has been on infants' use of featural information (Xu & Carey, 1996; Wilcox & Baillargeon, 1998a,b). The findings suggest that infants, like adults, can use featural information to individuate objects in occlusion events. However, whether infants demonstrate this ability depends on the method used to assess it. Two kinds of tasks have been used: event-mapping and event-monitoring. In a typical *event-mapping* task, infants first see an event in which either one object or two different objects are seen successively to each side of a screen. Next, the screen is removed, and infants are shown a test display involving either one or two objects. We have argued that in order to respond correctly to each test display, infants must retrieve a representation of the first event, map it onto the display before them, and judge whether the two are consistent (Wilcox & Baillargeon, 1998a). In a typical *event-monitoring* task, infants also watch an event in which either one object or two objects emerge successively to each side of a screen. However, the screen is *not* removed. As the event unfolds, infants must judge whether successive portions of the event are consistent. The main difference between the two tasks, then, is that event mapping requires infants to determine whether two separate and distinct events are mutually consistent, whereas event monitoring requires infants to judge whether one event is internally consistent.

Recent research indicates that event-monitoring is the more sensitive of the two measures. When an event-monitoring task is used, infants as young as 4.5 months of age succeed at using featural information to individuate objects in an occlusion event (Wilcox & Baillargeon, 1998a,b). In contrast, when an event-mapping task is used, infants younger than 11.5 months of age often fail to demonstrate this ability (Xu & Carey, 1996; Wilcox & Baillargeon, 1998a). For example, in one event-monitoring experiment (Wilcox & Baillargeon, 1998b), 4.5- and 7.5-month-old infants saw one of two events: a ball-box or a ball-ball event. In the ball-box event, a ball moved behind the left edge of a screen; after a brief interval, a box appeared at the screen's right edge. Next, the box returned behind the screen, and the ball emerged and returned to its starting position. The entire ball-box sequence repeated until the end of the trial. The ball-ball event was identical to the ball-box event, except that a ball, rather than a box, emerged to the right of the screen. Infants saw the ball-box or ball-ball event with either a wide screen or a narrow screen; the wide screen was sufficiently wide to hide the ball and box simultaneously, whereas the narrow screen was too narrow to hide both objects at the same time (although it was wide enough to hide the ball or box alone). The 4.5- and 7.5-month-old infants looked reliably longer at the ball-box event when it was seen with the narrow than the wide screen. In contrast, the infants looked equally at the ball-ball event when it was seen with the narrow or the wide screen. These results suggest that the infants: (a) concluded that the ball-box event involved two objects and the ball-ball event involved one object; (b) judged that the ball and box could fit simultaneously behind the wide but not the narrow screen, and that the ball could fit behind either screen; and hence (c) were surprised when the ball and box were both occluded by the narrow screen. When the task required the infants to judge whether the event before them was internally consistent – was seeing the object emerge to the right of the screen consistent with the width of the screen and the object seen to the left of the screen? – even the 4.5-month-old infants demonstrated the ability to use featural information to reason about the number of objects involved in the occlusion event.

3. Related findings: object segregation studies

The research described above indicates that when the objects seen to each side of an occluder are featurally distinct, infants as young as 4.5 months of age use these differences to conclude that two separate objects are involved in the event. In contrast, when the objects seen to each side of an occluder share the same features, infants assume that only one object is involved in the event. Furthermore, infants can correctly judge whether the screen is sufficiently wide to hide the two objects simultaneously. These results, along with other results obtained with event-monitoring tasks (Wilcox & Baillargeon, 1998a), are the first to provide evidence that infants as young as 4.5 months of age can use featural information to individuate objects that move in and out of view.

These results are also consistent with those obtained in recent investigations of infants' ability to segregate partly occluded displays. For example, some researchers have reported that infants can use featural information to interpret partly occluded displays (Needham & Baillargeon, 1997, 1998; Needham et al., 1997; Needham, 1998a). In these experiments, infants are typically presented with a static display that contains surfaces visible to each side of an occluder. Infants' task is to determine whether the two surfaces are connected behind the occluder, and hence constitute one object, or are not connected, and hence comprise two separate and distinct objects. In some cases, the surfaces seen to each side of the screen are similar; in other cases the surfaces are dissimilar. Since the surfaces are stationary at the beginning of the trial, and are aligned in the same depth plane, only featural information can be used to determine whether the surfaces belong to one object or to two different objects. For example, in one object segregation experiment, 4.5-month-olds received familiarization trials in which they saw a stationary, dissimilar partly occluded display (Needham, 1998a). This display consisted of a yellow cylinder and a tall blue box that protruded from behind the left and right edges, respectively, of a tall narrow screen. Next, the infants received test trials in which a hand grasped the cylinder and moved it back and forth toward and away from the screen. For half of the infants (move-together condition), the box moved with the cylinder; for the other infants (move-apart condition), the box remained stationary. The infants in the move-together condition looked reliably longer than those in the move-apart condition. These and control results indicated that the infants: (a) were led by the featural differences between the cylinder and box to conclude that they were two distinct objects; and (b) expected the cylinder to move alone and were surprised when it did not. These and related findings (see Needham et al., 1997, for a review) suggest that infants as young as 4.5 months of age can use featural information to judge how many objects are included in a partly occluded display.

The parallels between individuation tasks involving occlusion events and object segregation tasks involving partly occluded displays are striking. In both tasks, infants are asked to judge how many distinct objects are present behind the occluder; in the former the surfaces are seen sequentially, whereas in the latter, the surfaces are seen simultaneously. It is not surprising, then, that the two tasks yield similar results. Further research is needed to determine whether the processes that underlie infants' ability to correctly interpret occlusion events and partially occluded displays are as similar as the results to date suggest.

4. Types of featural information: form features and surface features

The results reported by Wilcox and Baillargeon, (1998a,b), as well as Needham and her colleagues (Needham & Baillargeon, 1997, 1998; Needham et al., 1997; Needham, 1998a), provide strong evidence that by 4.5 months of age infants use featural information to reason about the number of distinct entities present in an occlusion situation. They also raise questions about the type of featural information to which infants are most sensitive. In the individuation task used by Wilcox and Baillargeon, and in the object segregation task used by Needham and her colleagues, the objects seen to each side of the occluder varied on many dimensions, including shape, pattern, texture, and color. The infants could have been using one or all of these featural differences to draw a conclusion about the number of objects present.

Object features can be grouped into two general categories: those features that specify three-dimensional *form*, such as shape, size, and rigidity and those features that constitute *surface* properties, such as pattern, color, and texture (De Yoe & Van Essen, 1988). Are infants equally sensitive to form features and surface features when reasoning about the number of objects involved in an occlusion event? The physical reasoning literature suggests a tentative answer to this question.

First, consider *form* features. There is an abundance of evidence pointing to infants' sensitivity to size information when predicting the outcome of physical events (Baillargeon, 1987; 1991; Baillargeon & Graber, 1987; Baillargeon & DeVos, 1991; Spelke et al., 1992; Sitskoorn & Smitsman, 1995; Aguiar & Baillargeon, 1998; Wilcox & Baillargeon, 1998a,b). For example, 4-month-old infants are able to compare the width of a ball to the width of an opening and to judge whether the ball can fit through the opening (Spelke et al., 1992). In addition, 5.5-month-old infants are able to compare the height of a rabbit to that of a window and to judge whether the rabbit should appear in the window (Baillargeon & Graber, 1987). Finally, our own studies indicate that infants as young as 4.5 months are able to compare the combined width of two objects to the width of a screen and to assess whether both objects can hide simultaneously behind the screen (Wilcox & Baillargeon, 1998a,b).

It is less clear that infants are sensitive to *surface* features when predicting the outcome of physical events. By about 2 months of age infants can reliably discriminate differences in pattern and color (Fantz, 1961; Banks & Salapatek, 1981, 1983; Teller & Bornstein, 1987; Brown, 1990; Banks & Shannon, 1993), and categorize visual stimuli based on perceptual properties (Bornstein, Kessen & Weiskopf, 1976; Hayne, Rovee-Collier & Perris, 1987; Catherwood, Crassini & Freiberg, 1989; Quinn, Eimas & Rosenkrantz, 1993; Eimas & Quinn, 1994). However, the extent to which young infants *use* pattern and color features when reasoning about physical events is not immediately apparent. Although there is evidence that surface features can, in some instances, influence infants' performance on physical reasoning tasks (Baillargeon, 1995), infants' use of surface features has not been systematically explored. The lack of evidence may be telling: in many physical situations surface features are simply irrelevant to the outcome of the event. For example, the color of the ball would not alter whether it can fit in the opening (Spelke et al., 1992); likewise, whether the rabbit's body was striped, dotted, or plain would not affect whether it should appear in the window (Baillargeon & Graber, 1987). Hence, infants may not be practiced at determining when surface features provide important information and at using this information effectively.

5. The present research

The present experiments built on the findings of Wilcox and Baillargeon, (1998a,b) by investigating 4.5- to 11.5-month-old infants' sensitivity to four object features: shape, size, pattern, and color. Infants were tested with the same event-monitoring task used by Wilcox and Baillargeon (1998b), except that only one feature was manipulated at a time. In each experiment, infants saw one of two kinds of events, a different-features event or a same-features event. In the different-features event, the objects seen to each side of the screen differed on one of the four object features. In the same-features event, the objects seen to each side of the screen were identical in appearance. Infants saw the different- or same-features event with either the narrow or the wide screen. The wide screen was sufficiently wide to conceal both objects at the same time, whereas the narrow screen was too narrow to hide both objects simultaneously.

To anticipate the results, when the objects seen to each side of the occluder differed in *shape* or *size*, 4.5-month-old infants responded as if they had used this difference to conclude that two distinct objects were involved in the event (Experiments 1 and 2). In contrast, when the objects varied in *pattern*, 4.5-month-old infants failed to use this difference to individuate the objects, whereas 7.5-month-old infants succeeded (Experiments 3A and 3B). Finally, it was not until 11.5 months of age that infants successfully used *color* information to reason about the number of objects involved in the occlusion event (Experiments 4A and 4B).

6. Experiment 1

Experiment 1 was designed to investigate 4.5-month-old infants' use of shape information to individuate objects in occlusion events. Infants were assigned to either a different-shape or same-shape condition. In the *different-shape condition* (Fig. 1) infants first saw a familiarization event in which a green ball disappeared behind the left edge of a wide screen and, after a brief interval, a green box appeared at the right edge. The green box then disappeared back behind the screen and, after a brief pause, the ball emerged and returned to its starting position. The entire event cycle repeated until the end of the trial. Following the familiarization trials, infants saw a test event identical to the familiarization event with one exception: the screen was replaced by one of two novel screens. Both test screens differed from the familiarization screen in size: one screen was the same height as the familiarization screen, but was more narrow (narrow-screen condition), whereas the other screen was shorter than the familiarization screen, but the same width (wide-screen condition). Only the wide screen was wide enough to conceal both objects at the same time; the narrow screen was too narrow to hide the ball and box simultaneously. In the *same-shape condition* (Fig. 2) infants saw the same test events, except that a green ball appeared on both sides of the narrow or wide screen.

If the infants in the different-shape condition: (a) were led by the shape difference between the ball and box to view them as distinct objects; (b) appreciated that the combined width of the ball and box determined whether both objects could be concealed simultaneously behind the screen; and (c) judged that the ball and box could both be occluded by the wide but not the narrow screen, then the infants in the narrow-screen condition should be surprised when this judgment was violated. Because infants' surprise or puzzlement at an event typically manifests itself by prolonged looking at the event (Bornstein, 1985; Spelke, 1985), the infants in the narrow-screen condition should look reliably longer at the test event than the infants in the wide-screen condition. Furthermore, if the infants in the same shape-condition: (a) assumed, based on the featural similarities between the balls that appeared on either side of the screen, that they were the same ball; and (b) realized that the ball

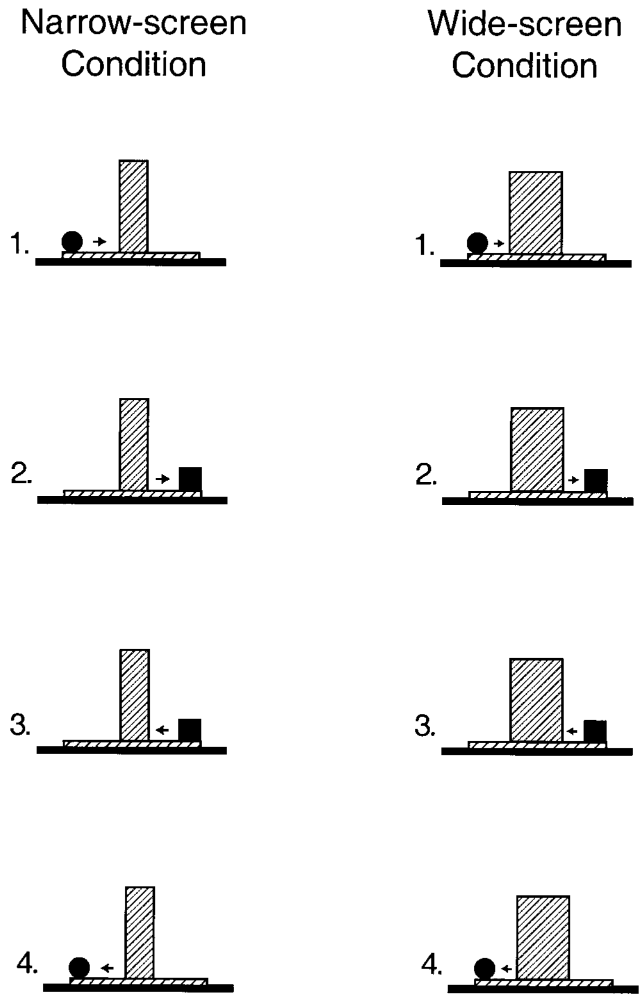

Fig. 1. Schematic drawing of the test events in the different-shape narrow- and wide-screen conditions in Experiment 1.

could be occluded by the wide or the narrow screen, then the infants in the narrow- and the wide-screen conditions should look equally during the test event.

7. Method

7.1. Subjects

Subjects were 28 healthy full-term infants, 14 male and 14 female (M = 4 months, 16 days; range = 4 months, 1 day to 5 months, 14 days). Eleven

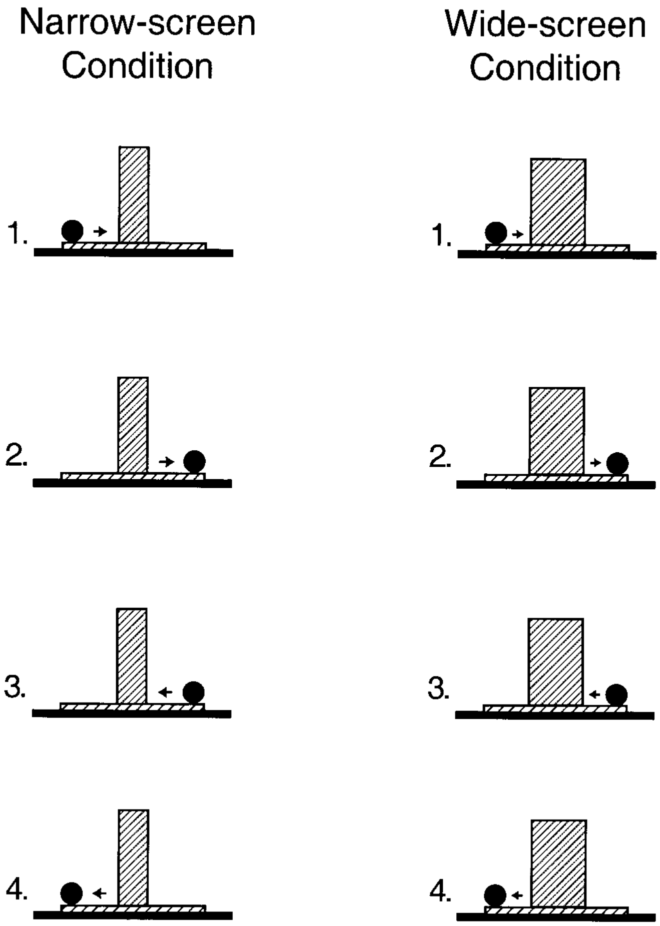

Fig. 2. Schematic drawing of the test events in the same-shape narrow- and wide-screen conditions in Experiment 1.

additional infants were tested but eliminated because they failed to complete six valid test trials, four because of fussiness, four because of sleepiness, two because of procedural problems, and one because the primary observer was unable to determine the direction of the infant's gaze. Seven infants were randomly assigned to each of the four experimental groups formed by crossing the two shape conditions (different versus same) and the two screen conditions (narrow versus wide): different-shape narrow-screen ($M = 4$ months, 13 days); different-shape wide-screen ($M = 4$ months, 13 days); same-shape narrow-screen ($M = 4$ months, 20 days); and same-shape wide-screen ($M = 4$ months, 19 days). In this and the following experiments, the infants' names were obtained from birth announcements in the local newspaper. Parents were contacted by letter and follow-up phone calls.

7.2. Apparatus and stimuli

The apparatus consisted of a wooden cubicle 213 cm high, 105 cm wide, and 43.5 cm deep. The infant sat facing an opening 51 cm high and 93 cm wide in the front wall of the apparatus. The floor of the apparatus was covered with cream colored contact paper, the side walls were painted cream, and the back walls were covered with patterned contact paper. A platform 1.5 cm tall, 60 cm wide, and 19 cm deep and covered with patterned contact paper lay 4.5 cm from the back wall and centered between the left and right walls; a 6 cm wide piece of light blue flannel lay lengthwise down the center of the platform.

The box was 10.25 cm square, made of Styrofoam, and painted green. The ball was 10.25 cm in diameter, made of Styrofoam, and painted green. The ball and box each rested on a clear Plexiglas base 10 cm wide, 6.5 cm deep, and 0.3 cm thick. Each base had a handle 16 cm long that protruded through an opening 3.25 cm high between the back wall and floor of the apparatus; the opening was partly concealed by cream-colored fringe. By moving the Plexiglas handle, an experimenter could move the ball and box left and right along the platform. The experimenter's hand holding the Plexiglas handle was concealed from the infants' view by the ball or box, the back wall, and the fringe covering the slit; as an added precaution, the hand also wore a cream-colored glove that blended with the fringe. To equate the procedures used in the ball-box and ball-ball conditions, two identical balls were used in the ball-ball condition.

The screen used in the familiarization trials was 30 cm wide and 41 cm high; it was made of yellow cardboard and covered with clear contact paper. The narrow test screen was 15.5 cm wide and 41 cm high and the wide test screen was 30 cm wide and 33 cm high; the narrow test screen thus differed from the familiarization screen in width and the wide test screen in height. Both test screens were made of blue cardboard, were decorated with small gold and silver stars, and were covered with clear contact paper. The screens were mounted on a wooden stand that was centered in front of the platform.

Embedded in the center of the platform was a metal bi-level composed of an upper and a lower shelf 16 cm apart; each shelf was 12.7 cm wide, 13 cm deep, and 0.2 cm thick. The upper shelf was level with the top of the platform and the bottom shelf extended underneath the platform. The bi-level could be lifted by means of a handle 19 cm long that protruded through an opening 19.5 cm high and 7 cm wide in the apparatus's back wall; when the bi-level was lifted, its lower shelf became level with the platform. The bi-level remained hidden behind the screen in its raised position.

A muslin-covered shade was lowered in front of the opening in the front wall of the apparatus at the end of each trial. Two muslin-covered wooden frames, each 213 cm high and 68 cm wide, stood at an angle on either side of the apparatus. These frames isolated the infants from the experimental room. In addition to the room lighting, four 20-W fluorescent bulbs were affixed to the inside walls of the apparatus (one on each wall).

7.3. Events

7.3.1. Different-shape narrow-screen condition

7.3.1.1. Familiarization event At the start of each familiarization trial, the ball sat with its center 6 cm from the left end of the platform. The familiarization screen stood upright and centered in front of the platform, and the box sat on the lower shelf of the bi-level.

Each familiarization trial began with a brief pretrial during which the observers monitored the infant's looking at the ball until the computer signaled that the infant had looked for one cumulative second. After a 1-s pause, the ball moved to the right until it reached the upper shelf of the bi-level behind the screen (2 s), the handle of the ball's base aligned with the handle of the bi-level. Next, the bi-level was lifted until its lower shelf was level with the platform (1 s); the box then emerged from behind the screen and moved to the right until its center was 6 cm from the right end of the platform (2 s). After a 1-s pause, the box returned to the bi-level (2 s) which was lowered (1 s) until its top shelf was once again even with the platform; the ball then returned to its starting position at the left end of the platform (2 s). The ball and box moved at a speed of about 12 cm/s. The 12-s event sequence just described was repeated continuously until the trial ended.

7.3.1.2. Test event The test event was identical to the familiarization event except that the familiarization screen was replaced with the narrow test screen.

7.3.2. Different-shape wide-screen condition

The familiarization and test events in the different-shape wide-screen condition were identical to those in the different-shape narrow-screen condition except that the narrow test screen was replaced with the wide test screen.

7.3.3. Same-shape narrow- and wide-screen conditions

The familiarization and test events in the same-shape narrow- and wide-screen conditions were identical to those in the different-shape narrow- and wide-screen conditions, respectively, with one exception: the box was replaced with a second, identical ball.

7.4. Procedure

The infant sat on a parent's lap centered in front of the apparatus. The infant's head was approximately 78 cm from the objects on the platform. The parent was asked not to interact with the infant while the experiment was in progress and to close his or her eyes during the familiarization and test trials.

Each infant participated in a two-phase procedure that consisted of a familiarization and a test phase. During the *familiarization* phase, the infants saw the familiarization event appropriate for their condition on six successive trials. Each trial ended when the infant: (a) looked away for two consecutive seconds after having looked at the event for at least 12 cumulative seconds (beginning at the end of the pretrial); or (b) looked for 60 cumulative seconds without looking away for two consecutive seconds. The 12-s minimum value was chosen to ensure that the infants had the opportunity to see one complete event cycle on each familiarization trial. During the *test* phase, the infants saw the test event appropriate for their condition on six successive trials. Each trial ended when the infant: (a) looked away for two consecutive seconds after having looked at the event for at least six cumulative seconds (beginning at the end of the pretrial); or (b) looked for 60 cumulative seconds without looking away for two consecutive seconds. The 6-s minimum value was chosen to ensure that the infants had the opportunity to observe the box or ball emerge to the right of the screen at least once on each test trial.

The infant's looking behavior was monitored by two observers who watched the infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers were not told, and could not determine, to which condition each infant was assigned[1]. Each observer held a button connected to a computer and depressed the button when the infant attended to the events. The looking times recorded by the primary observer determined when a trial had ended (see above) and were used in the data analyses. Each trial was divided into 100-ms intervals, and the computer determined in each interval whether the two observers agreed on the direction of the infant's gaze. Interobserver agreement was measured for 24 of the infants (for four of the infants data from only one observer was available) and was calculated for each test trial on the basis of the number of intervals in which the computer registered agreement out of the total number of intervals in the trial. Agreement averaged 90% per test trial per infant.

Preliminary analysis of the infants' mean looking times during the test trials did not yield a significant Sex × Shape Condition (different versus same) × Screen Condition (narrow versus wide) interaction, $F(1, 20) = 0.76$; the data were therefore collapsed across sex in subsequent analyses[2].

8. Results

8.1. Familiarization trials

The infants' looking times during the six familiarization trials (Fig. 3) were averaged and compared by means of a 2 × 2 analysis of variance (ANOVA), with Shape Condition (different versus same) and Screen Condition (narrow versus wide)

[1] The infants in Experiments 1–5 were presented with test events in which objects with the same or different features appeared on either side of a screen. For 138 of the 142 infants in these experiments, the primary observer was asked at the end of the test session whether the infant had seen a same- or a different-features event. The primary observer guessed correctly for only 71/138 infants, a performance not significantly different from chance (cumulative binomial probability, $P > 0.05$).

[2] Because of the small number of infants in each Sex × Object Condition × Screen Condition cell, this analysis needs to be interpreted with caution. The same caveat applies to the sex analyses in Experiments 2–4, which also yielded negative results.

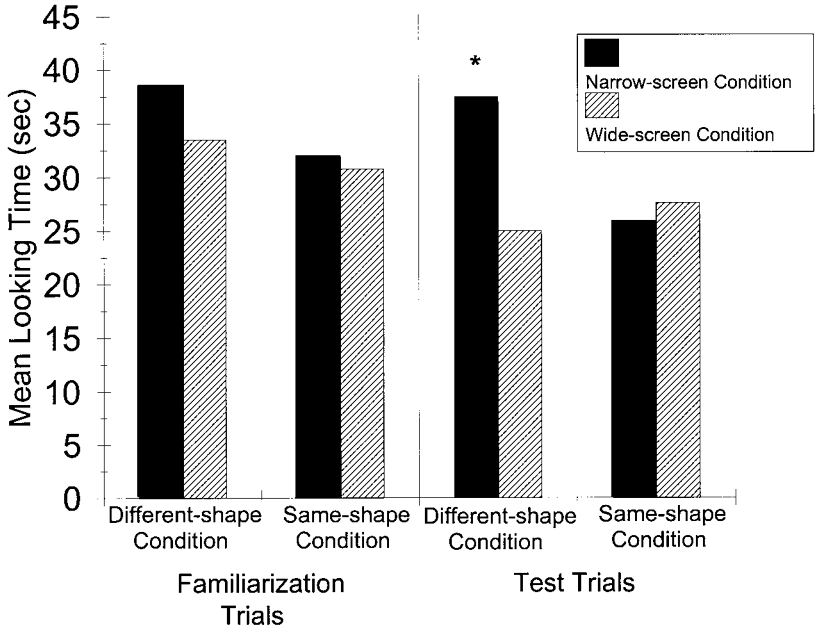

Fig. 3. Mean looking times of the 4.5-month-old infants in Experiment 1 during the familiarization and test trials.

as between-subjects factors. The main effects of Shape Condition, $F(1,24) = 1.59$, and Screen Condition, $F(1,24) = 0.71$, were not significant. In addition, the Shape Condition × Screen Condition interaction was not significant, $F(1,24) = 0.29$, indicating that the infants in the four different conditions did not differ reliably in their mean looking times during the familiarization trials (different-shape narrow-screen, $M = 38.6$, $SD = 8.7$; different-shape wide-screen, $M = 33.5$, $SD = 11.5$; same-shape narrow-screen, $M = 31.9$, $SD = 7.8$; and same-shape wide-screen, $M = 30.8$, $SD = 10.5$).

8.2. Test trials

The infants' mean looking times during the six test trials (Fig. 3) were averaged and analyzed in the same fashion as the familiarization trials. The main effects of Shape Condition, $F(1,24) = 2.38$, and Screen Condition, $F(1,24) = 3.38$, were not significant. However, the analysis yielded a significant Shape Condition × Screen Condition interaction, $F(1,24) = 5.95$, $P < 0.025$. Planned comparisons indicated that, in the different-shape condition, the infants who saw the narrow-screen event ($M = 37.5$, $SD = 8.3$) looked reliably longer than those who saw the wide-screen event ($M = 25.0$, $SD = 6.7$), $F(1,24) = 9.14$, $P < 0.01$; in the same-shape condition, no reliable difference was found between the looking times of the infants who saw the narrow-screen event ($M = 25.9$, SD = 96.3) or the wide-screen event ($M = 27.6$, SD = 9.3), $F(1, 24) = 0.17$[3].

9. Discussion

In the different-shape condition, the infants looked reliably longer when tested with the narrow as opposed to the wide screen. In contrast, in the same-shape condition, the infants tended to look about equally whether they were tested with the narrow or the wide screen. Together, these results suggest that the infants in the different-shape condition: (a) were led by the shape difference between the ball and box to conclude that they were two distinct objects; (b) judged that the ball and box could both be occluded by the wide but not the narrow screen; and hence (c) were surprised in the different-shape narrow-screen condition to see both objects out of view at the same time. In contrast, the infants in the same-shape condition: (a) were led by the featural similarities of the balls seen to each side of the screen to conclude that they were one and the same ball; (b) judged that the ball could fit behind either the wide or the narrow screen; and hence (c) found neither the wide- nor narrow-screen event surprising. These findings confirm earlier results that 4.5-month-old infants can use featural differences and similarities to draw conclusions about the number of objects involved in an occlusion event (Wilcox & Baillargeon, 1998b) and build on these findings by indicating the importance of shape to the process of object individuation.

10. Experiment 2

Given infants' success at using shape alone to individuate the objects in Experiment 1, Experiment 2 investigated 4.5-month-old infants' ability to use another form feature – size – to individuate objects. Infants were tested in either a different-size or same-size condition. In the *different-size condition* (Fig. 4), a large ball was seen to the left of the screen and a small ball to the right. The different-size event was seen with either the narrow or wide screen; the narrow screen was too narrow to occlude the large and small ball simultaneously, whereas the wide screen was sufficiently wide to conceal both balls at the same time. In the *same-size condition* (Fig. 5),

[3] Although the analysis of the familiarization data did not yield a significant main effect of object condition, there was nevertheless a tendency for the different-shape infants to look longer than the same-shape infants during the familiarization trials (Fig. 3). In light of this tendency, the test data were also subjected to an analysis of covariance (ANCOVA); the factors were the same as in the ANOVA, and the covariate was the infants' mean familiarization looking times. The purpose of this analysis was to examine whether the same test results would be obtained after adjusting for the differences in familiarization looking times between the infants in the different- and same-shape conditions. The results of the ANCOVA replicated those of the ANOVA: the Shape Condition × Screen Condition interaction was significant, $F(1, 23) = 5.82$, $P < 0.025$, and planned comparisons confirmed that the different-shape infants looked reliably longer at the narrow- than at the wide-screen event, $F(1, 23) = 9.18$, $P < 0.01$, whereas the same-shape infants looked about equally at the events, $F(1, 23) = 0.16$.

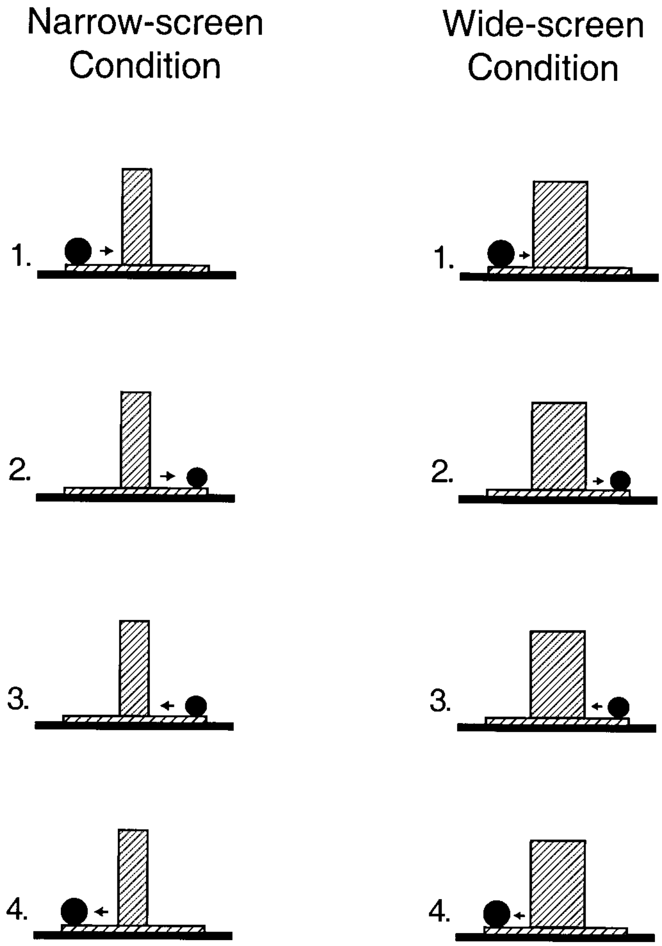

Fig. 4. Schematic drawing of the test events in the different-size narrow- and wide-screen conditions in Experiment 2.

infants saw a large ball to each side of the narrow or wide screen. If infants in the different-size condition: (a) used the discrepancy in size between the balls seen to each side of the screen to conclude that they were two distinct balls; and (b) judged that the large and small ball could fit simultaneously behind the wide but not the narrow screen, then they should look longer at the narrow- than at the wide-screen event. In contrast, if the infants in the same-size condition: (a) used the featural similarities between the large balls seen to the left and right of the screen to conclude that they were one and the same ball; and (b) understood that the large ball could fit behind either screen, then they should look equally at the narrow- and wide-screen events.

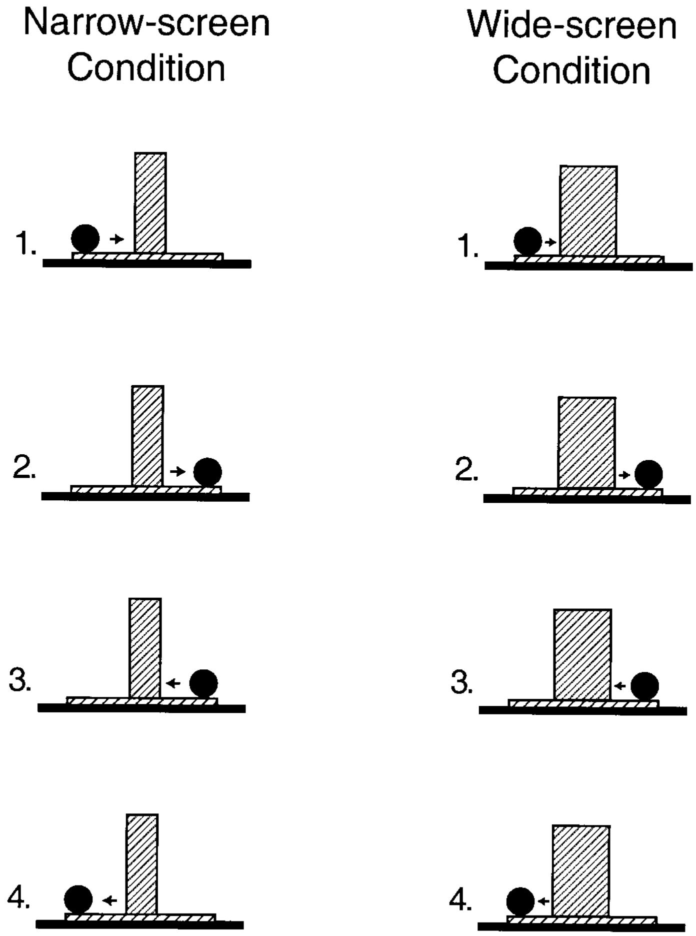

Fig. 5. Schematic drawing of the test events in the same-size narrow- and wide-screen conditions in Experiment 2.

10.1. Subjects

Subjects were 28 healthy full-term infants, 14 male and 14 female ($M = 4$ months, 16 days; range = 4 months, 1 day to 5 months, 17 days). Four additional infants were tested but eliminated, two because of fussiness and two because the primary observer was unable to determine the direction of the infant's gaze. Seven infants were randomly assigned to each of the four experimental conditions: different-size narrow-screen ($M = 4$ months, 14 days); different-size wide-screen ($M = 4$ months, 12 days); same-size narrow-screen ($M = 4$ months, 19 days); and same-size wide-screen ($M = 4$ months, 19 days).

10.2. Apparatus and stimuli

The apparatus and stimuli used in Experiment 2 were identical to those used in Experiment 1, with two exceptions. First, the ball and box were replaced by a large ball and a small ball. The large ball was 12.5 cm in diameter and the small ball was 7.5 cm in diameter; both balls were made of Styrofoam and painted green. Second, since the large ball was too wide to fit onto the bottom shelf of the bi-level, only one ball was used in the same-size condition (rather than two identical balls) and it always rested on the top shelf of the bi-level when behind the screen. To prevent observers from distinguishing between the two conditions based on faint noise cues, the experimenter raised and lowered the bi-level half-way each time the large ball was behind the screen.

10.3. Events

10.3.1. Different-size narrow- and wide-screen conditions

The familiarization and test events in the different-size narrow- and wide-screen conditions were identical to those in the different-shape narrow- and wide-screen conditions in Experiment 1, except that the large ball was seen to the left of the screen and the small ball to the right. The large ball was lifted on the top shelf of the bi-level and the small ball emerged from the bottom shelf.

10.3.2. Same-size narrow- and wide-screen conditions

The familiarization and test events in the same-size narrow- and wide-screen conditions were identical to those in the different-size narrow- and wide-screen conditions, respectively, with two exceptions. First, the large ball was seen on both sides of the screen. Second, since only the top shelf of the bi-level was used, the timing of the event was slightly different. Each time the large ball was behind the screen the bi-level was raised half-way and then lowered (rather than being fully raised *or* lowered), so that the large ball could emerge to both sides of the screen.

10.4. Procedure

The procedure used in Experiment 2 was identical to that used in Experiment 1. Interobserver agreement was measured for 25 of the infants and averaged 89% per test trial per infant.

Preliminary analysis of the infants' mean looking times during the test trials did not yield a significant Sex $\times$ Size Condition (different versus same) $\times$ Screen Condition (narrow versus wide) interaction, $F(1, 20) = 0.06$; the data were therefore collapsed across sex in subsequent analyses.

11. Results

11.1. Familiarization trials

The infants' looking times during the six familiarization trials (Fig. 6) were averaged and compared by means of a 2 × 2 ANOVA, with Size Condition (different versus same) and Screen Condition (narrow versus wide) as between-subjects factors. The main effects of Size Condition, $F(1, 24) = 0.51$, and Screen Condition, $F(1, 24) = 0.97$, were not significant. However, the Size Condition × Screen Condition interaction was significant, $F(1, 24) = 8.55$, $P < 0.01$, indicating that the infants in the four conditions differed in their mean looking times during the familiarization trials (different-size narrow-screen, $M = 32.8$, SD = 13.3; different-size wide-screen, $M = 25.5$, SD = 9.8; same-size narrow-screen, $M = 24.5$, SD = 7.3; and same-size wide-screen, $M = 39.2$, SD = 8.5). Post-hoc comparisons were made using the Tukey test. For the infants who saw the different-size event, the looking times of the infants in the narrow-screen and wide-screen conditions did not vary reliably. In contrast, for the infants who saw the same-size event, the infants in the wide-screen condition looked reliably longer during the familiarization trials than the infants in the narrow-screen condition, $P < 0.05$. Since the infants in the narrow- and wide-screen conditions saw exactly the same familiarization event, these differences most likely reflect random sampling error.

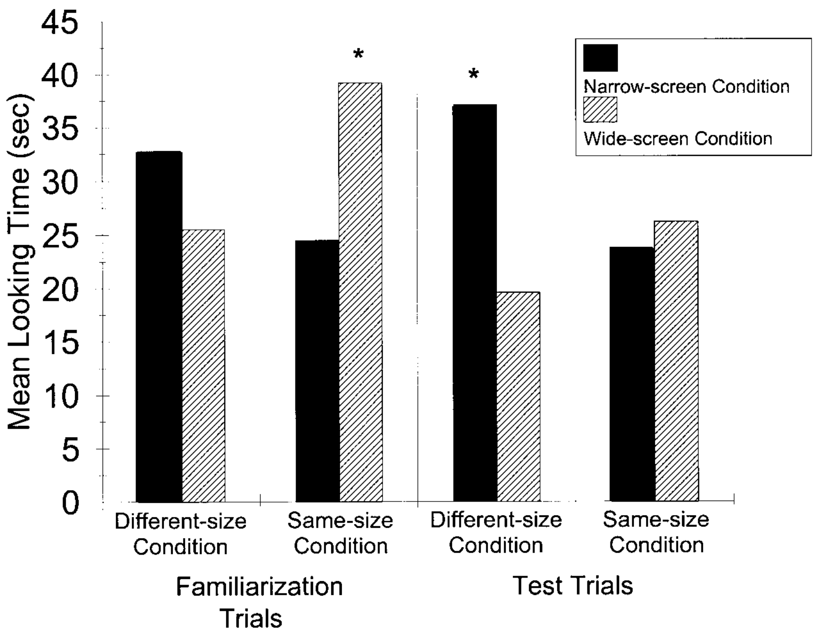

Fig. 6. Mean looking times of the 4.5-month-old infants in Experiment 2 during the familiarization and test trials.

11.2. Test trials

The infants' mean looking times during the six test trials (Fig. 6) were averaged and analyzed in the same fashion as the familiarization trials. The analysis yielded a significant Size Condition × Screen Condition interaction, $F(1, 24) = 9.77$, $P < 0.01$. Planned comparisons indicated that, in the different-size condition, the infants who saw the narrow-screen event ($M = 37.0$, $SD = 3.7$) looked reliably longer than those who saw the wide-screen event ($M = 19.6$, $SD = 6.8$), $F(1, 24) = 14.87$, $P < 0.001$; in the same-size condition, no reliable difference was found between the looking times of the infants who saw the narrow-screen event ($M = 23.7$, $SD = 10.2$) and wide-screen event ($M = 26.2$, $SD = 10.9$), $F(1, 24) = 0.32$[4].

12. Discussion

When the objects seen to the left and right of the screen differed in size, the infants looked reliably longer at the narrow- than at the wide-screen event. In contrast, when the objects seen to each side of the screen were identical in size, the infants looked about equally at the narrow- and wide-screen events. Together, these results suggest that the infants: (a) concluded that the different-size event involved two objects and the same-size event one object; (b) realized that the large ball and small ball could fit simultaneously behind the wide but not the narrow screen, and that the large ball could fit behind either screen; and hence (c) were surprised when the large ball and small ball were both out of view behind the narrow screen. These results extend the findings of Experiment 1 by providing evidence that infants use a difference in size, as well as a difference in shape, to individuate objects. Together, the results of Experiments 1 and 2 provide converging evidence that infants are sensitive to form features when reasoning about the number of objects present in an occlusion event.

One might question how the 4.5-month-old infants in the different-features conditions in Experiments 1 and 2 could have been so successful at judging whether the two objects could be concealed simultaneously behind the screen. Remember that during the event only one object was in view at a time, and there was a period of time when both objects were out of view. In light of recent evidence that young infants are limited in their ability to accurately represent absolute quantities (Baillargeon, 1995, 1998; Baillargeon, Kotovsky & Needham, 1995), the width-comparison task

[4] Since the infants in the different-size and same-size conditions evidenced different patterns of looking during the familiarization trials, looking times to the test event were subjected to an ANCOVA, as in Experiment 1, with the infants' mean familiarization looking times as the covariate. This analysis was conducted to examine whether the same test results would be obtained after adjusting for difference in familiarization looking times. The results of the ANCOVA replicated those of the ANOVA: the Size Condition × Screen Condition interaction was significant, $F(1, 23) = 4.61$, $P < 0.05$, and planned comparisons confirmed that the different-size infants looked reliably longer at the narrow- than at the wide-screen event, $F(1, 23) = 12.74$, $P < 0.01$, whereas the same-size infants looked about equally at the two events, $F(1, 23) < 0.01$.

may appear quite formidable. This concern deserves two comments. First, the width violations in Experiments 1 and 2 were fairly substantial. In Experiment 1 the violation was 5 cm, or about 24% of width of two objects combined; in Experiment 2 the violation was 4.5 cm, or about 22% of the width of the two objects combined. Hence, even a rough estimate of the width of the two objects would lead infants to conclude that both objects could not both fit behind the narrow screen at the same time. Second, data collected with adult subjects suggests that width-violations involving moving occluded objects appear much larger than they really are. For example, in Wilcox & Baillargeon (1998a) adults were shown a narrow- and a wide-screen ball-box event similar to the narrow- and wide-screen different-shape events in Experiment 1, with two exceptions: (a) the ball and box differed in shape, pattern, and color; and (b) the combined width of the ball and box was 22 cm and the width of the narrow screen was 21 cm. After viewing the narrow-screen ball-box event, most adults correctly judged that the screen was too narrow to hide both objects simultaneously, and estimated that the screen would need to be, on average, 5.5 cm ($SD = 3.9$) wider to occlude both objects together. After viewing the wide-screen ball-box event, most adults judged that the screen was sufficiently wide to hide the ball and box at the same time and estimated, on average, that the screen could be 5.4 cm ($SD = 2.8$) more narrow and still occlude the two objects (the screen was actually 8 cm wider than the two objects combined). Hence, the adult subjects responded as if they perceived the combined width of the two objects as being greater than it really was. What led adults to respond in this manner? Evidence from the adult cognition literature suggests an answer to this question.

Recent research suggests that adults' memory for the orientation or position of a moving object often presents a forward bias – a shift in the direction of the object's real or implied motion (Freyd & Finke, 1984; 1985; Baillargeon, 1987; Hubbard & Bharucha, 1988; Hubbard, 1990; Verfaillie & d'Ydewalle, 1991; Freyd & Miller, 1992). Freyd and her colleagues termed this phenomenon 'representational momentum' and took it to indicate that adults cannot instantaneously halt the representation of an object's motion (Freyd, 1993). A similar phenomenon may occur when adults reason about ongoing occlusion events (rather than when they attempt to remember a past displacement event). The adults in Wilcox and Baillargeon (1998a) may have assumed, when watching the event, that after becoming occluded the ball or box pursued its trajectory for a short distance behind the screen, rather than stopping abruptly as soon as it disappeared from sight. Such an assumption would inflate the perception that the screen was too narrow to hide both the ball and box at the same time.

Recent research suggests that infants perceive moving occlusion events in much the same way: 7.5-month-old infants, like adults, are capable of detecting a narrow-screen violation of only 1 cm, as if they to have an inflated perception of the amount of space the objects occupy when behind the occluder (Wilcox & Baillargeon, 1998a). In Experiments 1 and 2 the width violations were 5 cm and 4.5 cm, respectively, much larger than the 1 cm violation shown to 7.5-month-olds and adults in Wilcox and Baillargeon (1998a). Given the larger width violation, and the likelihood that the infants perceived the violation as even greater, it is not surprising that the

4.5-month-olds in the different-features conditions judged the narrow screen as too narrow to hide both objects simultaneously.

13. Experiment 3A

The results of Experiments 1 and 2 provide strong evidence for the conclusion that 4.5-month-old infants use form features – shape and size – to individuate objects involved in an occlusion event. Will young infants use surface features as well? Experiments 3 and 4 were designed to test infants' ability to use two surface features – pattern (Experiments 3A and 3B) and color (Experiments 4A,B) – to individuate objects.

In Experiment 3A, 4.5-month-old infants saw a *different-pattern event* in which a green ball with dots disappeared behind one edge of a screen and a green ball with stripes appeared at the other edge. Infants saw the different-pattern event with either the narrow or the wide screen. As will quickly become evident, the 4.5-month-olds failed to use the pattern difference to individuate the objects, hence they were not tested with a same-pattern event.

13.1. Subjects

Subjects were 14 healthy full-term infants, seven male and seven female ($M = 4$ months, 20 days; range = 4 months, 5 days to 5 months, 5 days). Two additional infants were tested but eliminated, one because of fussiness and one because the primary observer was unable to determine the direction of the infant's gaze. Seven infants were randomly assigned to each of the two experimental conditions: different-pattern narrow-screen ($M = 4$ months, 19 days) and different-pattern wide-screen ($M = 4$ months, 21 days).

13.2. Apparatus and stimuli

The apparatus and stimuli used in Experiment 3A were identical to those used in Experiment 1, with one exception: the ball and box were replaced by a ball with dots and a ball with stripes. The ball with dots was made of styrofoam, 10.25 cm in diameter, and painted green with red, yellow, and blue dots. The dots were 2 cm in diameter and spaced approximately 2.5 cm apart. The ball with stripes was identical, except that the dots were replaced with stripes of the same color. The stripes were 1.3 cm wide and spaced approximately 2 cm apart.

13.3. Events

13.3.1. Different-pattern narrow- and wide-screen conditions

The familiarization and test events in the different-pattern narrow- and wide-screen conditions were identical to those in the different-shape narrow- and wide-screen conditions of Experiment 1, except that the ball with dots was seen to the left of the screen and the ball with stripes was seen to the right.

13.4. Procedure

The procedure used in Experiment 3A was identical to that used in Experiment 1. Interobserver agreement was measured for 13 of the infants and averaged 91% per test trial per infant.

Preliminary analysis of the infants' mean looking times during the test trials did not yield a significant Sex × Screen Condition (narrow versus wide) interaction, $F(1, 10) = 0.12$; the data were therefore collapsed across sex in subsequent analyses.

14. Results

14.1. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and compared by means of a one-way ANOVA with Screen Condition (narrow versus wide) as the between-subjects factor. The main effect of Screen Condition was not significant, $F(1, 12) = 0.45$, indicating that the infants in the narrow-screen ($M = 35.1$, $SD = 12.2$) and wide-screen ($M = 31.7$, $SD = 6.5$) conditions looked about equally during the familiarization trials.

14.2. Test trials

The infants' mean looking times during the six test trials were averaged and analyzed in the same fashion as the familiarization trials. The main effect of Screen Condition was not significant, $F(1, 12) = 0.12$, indicating that the infants in the narrow-screen ($M = 28.0$, $SD = 7.6$) and wide-screen ($M = 26.3$, $SD = 10.2$) conditions looked about equally during the test trials.

15. Discussion

In contrast to the positive results obtained with 4.5-month-old infants in the different-shape (Experiment 1) and different-size (Experiment 2) conditions, the 4.5-month-old infants in the different-pattern condition looked about equally at the narrow- and wide-screen test events, as if they had failed to use the difference in pattern to individuate the objects involved in the occlusion event. There are several possible interpretations of these negative results. It could be that the infants: (a) failed to detect the difference in the balls' pattern; (b) detected the difference in pattern, but did not realize that pattern information could be used to draw inferences about the number of objects present in the event; or (c) were capable of using pattern to individuate objects, but failed to do so in the present experimental context. Each of these three possibilities will be considered in turn.

The first possibility suggests that because of limited visual capacities, the infants did not perceive the difference in pattern. If the infants failed to discriminate between the dotted and striped patterns on the two balls, they would have no reason to believe that more than one object was involved in the event. Findings from the infant perception literature cast serious doubts on this interpretation. Research indicates that by 2 to 3 months of age infants are quite competent at discriminating differences in pattern, especially those high in contrast (Fantz, 1961; Banks & Salapatek, 1981). At about the same time, infants evidence a change in visual scanning behavior: they shift their attention away from the external boundaries of a visual stimulus and begin to systematically examine and explore the internal elements (Salapatek, 1975; Maurer, 1983; Bronson, 1991). Hence, by 4.5 months of age infants are proficient at distinguishing between visual stimuli that contain patterns with distinctive internal elements. In the present experiment, the patterns on the two balls were very distinct: one consisted of brightly color dots whereas the other involved brightly colored lines. Even a cursory examination of the features displayed on the surface of each ball would have been sufficient to ascertain that the ball seen to each side of the screen presented different patterns. In light of this evidence, it is unlikely that the infants in Experiment 3A failed to individuate the objects because they were unable to detect the difference between the dotted and the striped ball.

This leads us to consider the other two possible interpretations. On the one hand, it is possible that the 4.5-month-olds perceived the difference in pattern, but did not know to use this difference to individuate the objects; perhaps the infants had not yet learned that pattern information can be used to keep track of the identity of objects involved in occlusion events. Alternatively, it is possible that the 4.5-month-olds understood that pattern can be used to individuate objects, but were not inspired to do so in the present experimental context; because of processing biases (possible sources of biases are discussed in the section 25), the infants failed to consider pattern as relevant to the occlusion event. Although the current data are insufficient to conclusively decide between these two equally plausible interpretations, recent results from object segregation studies suggest that the first of these is the most likely. Needham (1998b) reported that 4-month-olds use shape but not pattern information to segregate stationary adjacent surfaces. Likewise, Craton, Poirier and Heagney (1998) found that 7- but not 4-month-olds use pattern to parse partly occluded arrays. These results, together with the negative results obtained in the present experiment, indicate that infants fail, in a variety of settings, to draw on pattern information to reason about the number of distinct objects present in a visual display. This evidence, coupled with the fact that infants do not use pattern even when pattern differences are made quite obvious – when the different patterns are seen side by side (Needham, 1998b) or to each side of a very narrow screen (Craton et al., 1998) – suggests that infants simply do not recognize pattern as a useful source of information when individuating objects.

16. Experiment 3B

Despite the poor performance of the 4.5-month-old infants' in Experiment 3A, it is quite possible that slightly older infants would succeed at using a pattern difference to individuate objects in occlusion events: recall that 7-month-olds use pattern information to segregate static partly occluded displays (Craton et al., 1998). To explore this possibility, 7.5-month-old infants were tested using a procedure similar to that used in Experiment 3A, except that infants were assigned to either a different- or a same-pattern condition. Infants in the *different-pattern condition* saw the different-pattern event described in Experiment 3A, with either the narrow or the wide screen. Infants in the *same-pattern condition* saw a similar event, except that a ball with dots was seen to each side of the narrow or wide screen.

16.1. Subjects

Subjects were 24 healthy full-term infants, 12 male and 12 female ($M = 7$ months, 18 days; range = 7 months, 4 days to 8 months, 3 days). Three additional infants were tested but eliminated because of procedural problems. Six infants were randomly assigned to each of the four experimental conditions: different-pattern narrow-screen ($M = 7$ months, 18 days); different-pattern wide-screen ($M = 7$ months, 20 days); same-pattern narrow-screen ($M = 7$ months, 15 days); and same-pattern wide-screen ($M = 7$ months, 18 days).

16.2. Apparatus and stimuli

The apparatus and stimuli used in Experiment 3B were identical to those in Experiment 3A. In addition, two identical balls with dots were used in the same-pattern condition.

16.3. Events

16.3.1. Different-pattern narrow- and wide-screen conditions

The familiarization and test events in the different-pattern narrow- and wide-screen conditions were identical to those in the different-pattern narrow- and wide-screen conditions of Experiment 3A.

16.3.2. Same-pattern narrow- and wide-screen conditions

The familiarization and test events in the same-pattern narrow- and wide-screen conditions were identical to those in the different-pattern narrow- and wide-screen conditions, respectively, with one exception: a ball with dots rather than a ball with stripes was seen to the right of the screen.

16.4. Procedure

The procedure used in Experiment 3B was the same as that in Experiment 3A, except that the infants saw two rather than six test trials. In previous research with infants 4.5 to 11.5 months of age, we have found that older infants tend to become less attentive and more fussy as the experiment progresses, and so are typically given fewer trials (Wilcox & Baillargeon, 1998a,b). Interobserver agreement was measured for 22 of the infants and averaged 95% per test trial per infant.

Preliminary analysis of the infants' mean looking times during the test trials did not yield a significant Sex × Pattern Condition (different versus same) × Screen Condition (narrow versus wide) interaction, $F(1, 16) = 0.65$; the data were therefore collapsed across sex in subsequent analyses.

17. Results

17.1. Familiarization trials

The infants' looking times during the six familiarization trials (Fig. 7) were averaged and compared by means of a 2 × 2 ANOVA, with Pattern Condition (different versus same) and Screen Condition (narrow versus wide) as between-subjects factors. The main effects of Pattern Condition, $F(1, 20) = 0.46$, and Screen Condition, $F(1, 20) = 0.08$, were not significant. The Pattern Condition × Screen Condition interaction was not significant, $F(1, 20) = 1.04$, indicating that the infants in the four different conditions did not differ reliably in their mean looking times during the familiarization trials (different-pattern narrow-screen, $M = 37.8$, SD = 9.3; different-pattern wide-screen, $M = 33.5$, SD = 6.2; same-pattern narrow-screen, $M = 32.3$, SD = 10.6; and same-pattern wide-screen, $M = 34.6$, SD = 3.7).

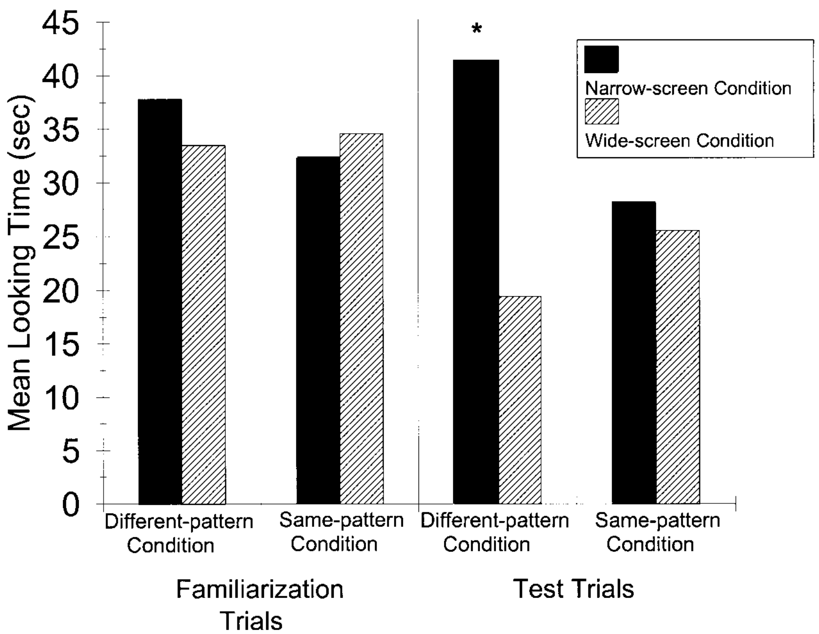

Fig. 7. Mean looking times of the 7.5-month-old infants in Experiment 3B during the familiarization and test trials.

17.2. Test trials

The infants' mean looking times during the two test trials (Fig. 7) were averaged and analyzed in the same fashion as the familiarization trials. The main effect of Pattern Condition, $F(1,20) = 0.82$, was not significant. The main effect of Screen Condition, $F(1,20) = 9.38$, was significant, $P < 0.01$. The analysis also yielded a significant Pattern Condition × Screen Condition interaction, $F(1,20) = 5.83$, $P < 0.05$. Planned comparisons indicated that, in the different-pattern condition, the infants who saw the narrow-screen event ($M = 41.4$, SD = 8.9) looked reliably longer than those who saw the wide-screen event ($M = 19.4$, SD = 11.9), $F(1,20) = 15.00$, $P < 0.001$; in the same-pattern condition, no reliable difference was found between the looking times of the infants who saw the narrow-screen event ($M = 28.1$, SD = 8.0) or the wide-screen event ($M = 25.5$, SD = 10.0), $F(1,20) = 0.21$[5].

18. Discussion

The 7.5-month-olds in Experiment 3B looked reliably longer at the different-pattern event when it was seen with the narrow as opposed to the wide screen. In contrast, the infants looked about equally at the same-pattern event whether it was seen with the narrow or the wide screen. These results suggest that the infants in the different-pattern condition: (a) concluded that the ball with dots, seen to the left of the screen, and the ball with stripes, seen to the right of the screen, constituted two separate and distinct balls; and (b) judged that both balls could not be concealed behind the narrow screen at the same time. Furthermore, these results suggest that the infants in the same-pattern condition used the featural similarity of the balls seen to each side of the screen to conclude that only one ball was involved in the test event.

19. Experiment 4A

The positive results obtained with the 7.5-month-olds in the different-pattern condition raised the possibility that infants this age might be able to use other surface features, such as color, to individuate occluded objects. The next two experiments investigated this possibility. Experiment 4A tested 7.5- and 9.5-month-old infants' ability to use a color difference to draw conclusions about the number of distinct objects involved in an occlusion event. A procedure similar to that of Experiment 3A was used, except that the object seen to each side of the screen differed in color

[5] To be consistent with Experiments 1 and 2, the test data were subjected to an ANCOVA using the infants' mean familiarization looking times as the covariate. The results of the ANCOVA replicated those of the ANOVA: the Pattern Condition × Screen Condition interaction was again significant, $F(1,19) = 5.02$, $P < 0.05$, and planned comparisons confirmed that the different-pattern infants looked reliably longer at the narrow- than at the wide-screen event, $F(1,19) = 13.88$, $P < 0.01$, whereas the same-pattern infants looked about equally at the events, $F(1,19) = 0.23$.

rather than pattern. In the *different-color event* a green ball disappeared behind the left edge of the screen and a red ball appeared at the right edge; the event was seen with either a wide or a narrow screen. If the infants were able to use the difference in color to conclude that the event involved two numerically distinct objects, then they should find the narrow- but not the wide-screen event surprising.

19.1. Subjects

Subjects were 12 7.5-month-old infants, six male and six female ($M = 7$ months, 17 days; range = 7 months, 5 days to 7 months, 28 days) and 12 9.5-month-old infants, six male and six female ($M = 9$ months, 14 days; range = 9 months, 1 day to 9 months, 28 days). Infants were born healthy and full-term. Four additional infants were tested but eliminated, two because of fussiness and two because of procedural problems. Six 7.5- and 9.5-month-old infants were randomly assigned to each of the two experimental conditions: different-color narrow-screen ($M = 7$ months, 17 days and $M = 9$ months, 14 days, respectively) and different-color wide-screen ($M = 7$ months, 17 days and $M = 9$ months, 14 days, respectively).

19.2. Apparatus and stimuli

The apparatus and stimuli used in Experiment 4A were identical to those used in Experiment 3A with one exception: the ball with dots and the ball with stripes were replaced by a green ball and a red ball, respectively. Both balls were made of Styrofoam and were 10.25 cm in diameter.

19.3. Events

19.3.1. Different-color narrow- and wide-screen conditions

The familiarization and test events in the different-color narrow- and wide-screen conditions were identical to those in the different-pattern narrow- and wide-screen conditions of Experiment 3A, except that a green ball was seen to the left of the screen and a red ball was seen to the right (the green and red ball were without pattern).

19.4. Procedure

The procedure used in Experiment 4A was identical to that used in Experiment 1. Interobserver agreement was measured for 20 of the infants and averaged 90% per test trial per infant.

Preliminary analysis of the infants' mean looking times during the test trials did not yield a significant Sex $\times$ Screen Condition (narrow versus wide) interaction, $F(1, 16) = 0.17$; the data were therefore collapsed across sex in subsequent analyses.

20. Results

20.1. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and compared by means of a one-way ANOVA with Screen Condition (narrow versus wide) and Age (7.5 versus 9.5 months) as the between-subjects factors. The main effects of Screen Condition, $F(1,20) = 0.50$, and Age, $F(1,20) = 2.37$, were not significant. In addition, the Screen Condition × Age interaction was not significant $F(1,20) = 0.83$. These results indicated that the infants in the narrow-screen ($M = 31.2$, $SD = 7.8$) and wide-screen ($M = 33.2$, $SD = 6.3$) conditions looked about equally at the familiarization event, and that looking times at the two events did not vary reliably across age.

20.2. Test trials

The infants' mean looking times during the two test trials were averaged and analyzed in the same fashion as the familiarization trials. The main effect of Screen Condition, $F(1,20) = 0.03$, was not significant, nor was the Screen Condition × Age interaction, $F(1,20) = 0.18$. These results indicated that the infants in the narrow-screen ($M = 23.6$, $SD = 10.7$) and wide-screen ($M = 24.5$, $SD = 16.3$) conditions looked about equally at the test event. The main effect of Age, $F(1,20) = 4.25$, approached significance, $P = 0.052$, suggesting that the younger infants ($M = 29.6$, $SD = 16.2$) tended to look longer at the test events than the older infants ($M = 18.6$, $SD = 7.1$).

21. Discussion

The 7.5- and 9.5-month-old infants in Experiment 4A looked about equally at the different-color narrow- and wide-screen test events, as if they had failed to use the color difference to individuate the objects involved in the events. These results, like the negative pattern results obtained in Experiment 3A, are open to several interpretations. It could be that the infants: (a) failed to detect the difference in the balls' color; (b) detected the difference in color, but did not realize that color information could be used to draw inferences about the number of objects present in the event; or (c) were capable of using color to individuate objects, but failed to consider color in the present experimental context. Each of these three possibilities will be considered.

Infant perception research suggests that the first possibility, that the infants were unable to detect the color difference, is unlikely. Newborns can discriminate between gray and colored stimuli (Adams, 1987) and by 2–3 months of age infants, like adults, are trichromatic and can discriminate colors across the entire spectrum (Brown, 1990; Banks & Shannon, 1993). By 4 months infants evidence color preferences similar to those of adults (Teller & Bornstein, 1987) and organize hues into categories (Bornstein et al., 1976; Catherwood et al., 1989). In light of this evidence, it is unlikely that the 7.5- and 9.5-month-olds in Experiment 4A were unable to discriminate between the green and red balls[6].

This leaves open the possibility that the infants failed because they were either incapable of using color to individuate objects or were not inspired to do so in the present experimental context. Although the current data are insufficient to decide between these two possibilities, preliminary experiments conducted by Chapa and Wilcox (1998) address this issue. These experiments examined whether infants could be induced to use color for the purpose of object individuation by changing the task context. In one experiment, for example, 9.5-month-old infants were tested using a procedure similar to that of Experiment 4A with one difference: prior to the familiarization and test events infants saw two pairs of pretest events. In the first pair of pretest events, infants saw a green can with a handle pound a nail; they then saw a red can with a handle pour salt (the two cans were identical except for their color). In the second pair of pretest events, infants saw the same two events except that the red and green cans were replaced with red and green cups; the red cup pounded and the green cup poured. The pretest events were followed by the familiarization and test events described in Experiment 4A. The 9.5-month-old infants looked reliably longer at the narrow- than at the wide-screen test event, as if viewing the pound/pour events in the pretest trials heightened their sensitivity to color in the test trials. Additional experiments revealed that if: (a) the actions the objects performed had no functional significance (i.e. lowering/tilting rather than pounding/pouring); or (b) infants saw the same object (i.e. a can) rather than two different objects (i.e. a can and a cup) on both pairs of pretest events, 9.5-month-old infants did not use the color difference to individuate the balls in the subsequent test trials. Together, these results suggest that: (a) when viewing physical events, 9.5-month-old infants form object categories that include function and color information; and (b) object categories formed when reasoning about one event (e.g. the pound/pour events) can influence infants' interpretation of another event (e.g. the occlusion event).

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[6] Additional data provide evidence that the infants could discriminate between the green and red balls in the present experimental conditions. Twelve 7.5-month-olds, six male and six female ($M = 7$ months, 17 days; range = 7 months, 5 days to 7 months, 28 days), were assigned to one of two conditions. Infants in the *familiar-color* condition saw familiarization and test events in which a green ball was seen to each side of a wide and narrow screen, respectively. Infants in the *novel-color* condition saw the same events with one exception: in the familiarization event a red ball was seen to each side of the screen. The same procedure as in Experiment 4A was used with two exceptions: (a) infants saw only one test trial; and (b) the familiarization trials and the test trial ended when the infant looked away for 1 s after have looked for a minimum of six consecutive seconds, or looked for 60 cumulative seconds. The infants in the familiar-color ($M = 22.2$, SD = 6.6) and novel-color ($M = 22.5$, SD = 16.4) condition looked about equally during the familiarization trials, $F(1, 10) < 0.01$. However, the infants in the novel-color condition ($M = 40.9$, SD = 15.4) looked reliably longer than the infants in the familiar-color condition ($M = 22.8$, SD = 11.9), during the test trial $F(1, 10) = 5.16$, $P < 0.05$. In addition, the novel-color infants looked reliably longer during the test trial than during the last three familiarization trials ($M = 20.2$, SD = 9.8), $t(1, 11) = 2.97$, $P < 0.05$, whereas in the familiar-color infants looked about equally ($M = 17.1$, SD = 16.7), $t(1, 11) = 1.23$. These results: (a) suggest that the infants in the novel-color condition detected the change in color; and (b) support the conclusion that the negative findings obtained in Experiment 4A cannot be attributed to infants' failure to discriminate between the green and red balls.

The results of the pound/pour experiments suggest that the 9.5-month-old infants in Experiment 4A failed to correctly interpret the different-color event as involving two distinct objects because they failed to attend to the balls' color in that context (possible reasons for this will be discussed in the section 25). Evidence that 9.5-month-old infants' sensitivity to color differences can be manipulated – after viewing events designed to highlight the functional value of attending to an object's color, they succeed on the individuation task – suggests that 9.5-month-olds are capable of using color to draw inferences about the number of objects involved in the event, even though they may not always do so spontaneously. What is left unclear is whether the 7.5-month-olds in Experiment 4A failed to use the color difference for the same reason, or whether they did not yet have the knowledge that color differences can signal the presence of distinct objects (i.e. like the 4.5-month-old infants in the pattern experiments).

The negative results obtained in Experiment 4A naturally raise the following question – At what age do infants spontaneously draw on color information to reason about object identity? The next experiment was conducted to answer this question.

22. Experiment 4B

Experiment 4B examined whether 11.5-month-olds would use a color difference to individuate the objects involved in an occlusion event. In this experiment, infants were assigned to one of two conditions: different-color or same-color. Infants in the *different-color* condition saw the different-color event described in Experiment 4A with either the narrow or the wide screen. Infants in the *same-color* condition saw a similar event, except that a green ball was seen to each side of the narrow or wide screen.

22.1. Subjects

Subjects were 24 healthy full-term infants, eight male and 16 female ($M = 11$ months, 13 days; range = 11 months, 2 days to 12 months, 3 days). One additional infant was tested but eliminated because of procedural problems. Six infants were randomly assigned to each of the four experimental conditions: different-color narrow-screen ($M = 11$ months, 11 days); different-color wide-screen ($M = 11$ months, 12 days); same-color narrow-screen ($M = 11$ months, 15 days); and same-color wide-screen ($M = 11$ months, 14 days).

22.2. Apparatus and stimuli

The apparatus and stimuli used in Experiment 4B were identical to those used in Experiment 4A. In addition, two identical green balls were used in the same-color condition.

22.3. Events

22.3.1. Different-color narrow- and wide-screen conditions

The familiarization and test events in the different-color narrow- and wide-screen conditions were identical to those in the different-color narrow- and wide-screen conditions of Experiment 4A.

22.3.2. Same-color narrow- and wide-screen conditions

The familiarization and test events in the same-color narrow- and wide-screen conditions were identical to those in the different-color narrow- and wide-screen conditions, with one exception: a green ball rather than a red ball was seen to the right of the screen.

22.4. Procedure

The procedure used in Experiment 4B was identical to that in Experiment 4A with one exception: infants saw only 4 familiarization trials. This procedural change was introduced because older infants tended to lose interest in the experiment quickly, and decreasing the number of familiarization trials did not adversely affect the older infants' performance. Interobserver agreement was measured for 21 of the infants and averaged 93% per test trial per infant.

Preliminary analysis of the infants' mean looking times during the test trials did not yield a significant Sex $\times$ Color Condition (different versus same) $\times$ Screen Condition (narrow versus wide) interaction, $F(1, 16) = 1.27$; the data were therefore collapsed across sex in subsequent analyses.

23. Results

23.1. Familiarization trials

The infants' looking times during the four familiarization trials (Fig. 8) were averaged and compared by means of a 2×2 ANOVA, with Color Condition (different versus same) and Screen Condition (narrow versus wide) as between-subjects factors. The main effects of Color Condition, $F(1, 20) = 0.12$, and Screen Condition, $F(1, 20) = 0.14$, were not significant. In addition, the Color Condition $\times$ Screen Condition interaction was not significant, $F(1, 20) = 0.31$, indicating that the infants in the four different conditions did not differ reliably in their mean looking times during the familiarization trials (different-color narrow-screen, $M = 29.4$, SD = 4.3; different-color wide-screen, $M = 28.8$, SD = 7.1; same-color narrow-screen, $M = 26.6$, SD = 10.7; and same-color wide-screen, $M = 29.4$, SD = 5.7).

23.2. Test trials

The infants' mean looking times during the two test trials (Fig. 8) were averaged and analyzed in the same fashion as the familiarization trials. The main effect of Color Condition was significant, $F(1, 20) = 19.91$, $P < 0.001$. The main effect of Screen Condition, $F(1, 20) = 2.88$, was not significant. The analysis also yielded a significant Color Condition $\times$ Screen Condition interaction, $F(1, 20) = 4.71$, $P < 0.05$.

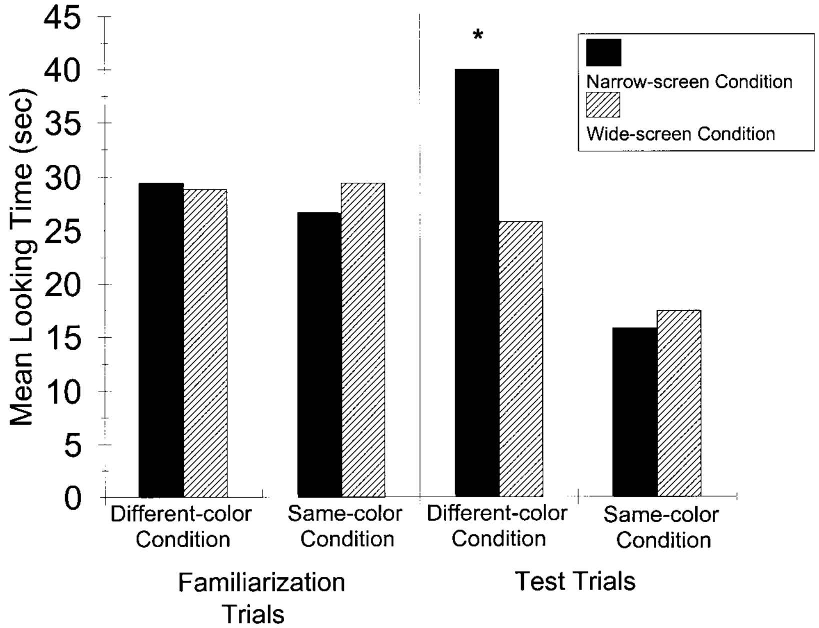

Fig. 8. Mean looking times of the 11.5-month-old infants in Experiment 4B during the familiarization and test trials.

Planned comparisons indicated that, in the different-color condition, the infants who saw the narrow-screen event ($M = 40.0$, SD = 11.3) looked reliably longer than those who saw the wide-screen event ($M = 25.8$, SD = 9.9), $F(1, 20) = 7.47$, $P < 0.025$; in the same-color condition, no reliable difference was found between the looking times of the infants who saw the narrow-screen ($M = 15.7$, SD = 6.1) or the wide-screen ($M = 17.4$, SD = 7.6) event, $F(1, 20) = 0.11$[7].

24. Discussion

The 11.5-month-old infants in the different-color condition looked reliably longer at the narrow- than at the wide-screen test event. In contrast, the infants in the same-color condition looked about equally at the two test events. These results suggest that the 11.5-month-old infants: (a) concluded that the green ball, seen to the left of the screen, and the red ball, seen to the right of the screen, constituted two distinct

[7] The test data were subjected to an ANCOVA using the infants' mean familiarization looking times as the covariate. The results of the ANCOVA replicated those of the ANOVA: the Color Condition × Screen Condition interaction was again significant, $F(1, 19) = 4.41$, $P < 0.05$, and planned comparisons confirmed that the different-color infants looked reliably longer at the narrow- than at the wide-screen event, $F(1, 19) = 7.11$, $P < 0.025$, whereas the same-color infants looked about equally at the events, $F(1, 19) = 0.11$.

balls; and (b) judged that the two balls could both be concealed behind the wide but not the narrow screen.

The positive results obtained with the 11.5-month-olds in the present experiment contrast sharply with the negative results obtained with the 7.5- and 9.5-month-olds in Experiment 4A, and present an intriguing picture of infants' sensitivity to color information when reasoning about occlusion events. Remember that infants as young as 2–3 months can discriminate between colors (Teller & Bornstein, 1987; Brown, 1990; Banks & Shannon, 1993), and by 4 months of age respond categorically to color, using the same basic categories as adults (Bornstein et al., 1976; Catherwood et al., 1989). Yet it is not until many months later that infants spontaneously use a color difference to draw inferences about the number of objects present in an occlusion event.

One interesting aspect of the present results is that they are very similar to those recently obtained in event-mapping experiments (Leslie, Xu, Tremoulet & Scholl, 1998). Remember that event-mapping tasks differ from event-monitoring tasks, like the one used in the present experiments, in that they require infants to: (a) retrieve a representation of one event; (b) compare it to a subsequent event; and (c) judge whether the two are consistent (Wilcox & Baillargeon, 1998a). For example, in one event-mapping experiment (Leslie et al., 1998) 12-month-old infants saw an event in which in a circle and a triangle emerged successively to the right of a screen. After several presentations of the circle-triangle event, the screen was removed. Infants then saw a display containing either a circle and a triangle or two triangles. The infants looked reliably longer at the two triangles, as if they had successfully mapped their representation of the circle-triangle event onto the final display. In contrast, when the objects that emerged to each side of the screen differed in color (i.e. a red circle and a green circle), rather than shape, the infants failed to detect whether a discrepancy existed between the initial event and the final display (i.e. either a green and red circle or two red circles). Additional experiments confirmed that the 12-month-olds used the color difference to individuate the objects – they expected to see two objects when the screen was removed-even though they failed to map the color information – they did not care what color the two objects were. The similarity of the present results to those of Leslie et al., (1998) are quite striking: just as infants use form features (i.e. shape and size) before surface features (i.e. pattern and color) to interpret occlusion events, infants are also more likely to retrieve information about an object's shape than its color when mapping event representations. What is left open to speculation is whether the same explanation can be offered for the developmental sequence observed in the two tasks, or whether different processes are involved. For example, the event-monitoring results may reflect a delay in infants' identification of pattern and color as important to reasoning about occlusion events, whereas the event-mapping results may reflect a limit in the amount and type of object information that infants can store and retrieve. In contrast, the form-to-surface features sequence observed in the two tasks may reflect an overall difficulty in incorporating pattern and color information when representing and reasoning about occlusion events.

25. Conclusion

The present research examined 4.5- to 11.5-month-old infants' ability to use two form features, shape and size, and two surface features, pattern and color, to individuate objects in occlusion events. Infants' sensitivity to these features was assessed using a task in which infants saw either a different-features occlusion event (i.e. the objects seen to each side of an occluder differed in shape, size, pattern, or color) or a same-features occlusion event (i.e. the objects seen to each side of an occluder were identical in appearance), with either a narrow or a wide screen. The results indicated that when the objects differed in shape or size, 4.5-month-old infants used the difference to conclude that two distinct objects were involved in the event, and correctly judged that both objects could fit behind the wide but not the narrow screen. Furthermore, when the objects seen to each side of the occluder were identical in appearance, 4.5-month-old infants used the featural similarities to conclude that a single object was present, and that it could fit behind either screen. In contrast, when the objects seen to each side of the occluder differed in pattern or color, young infants were less successful at correctly interpreting the occlusion event. It was not until 7.5 months that infants used a pattern difference, and until 11.5 months that infants used a color difference, to signal the presence of two distinct objects.

These results confirm previous findings that infants as young as 4.5 months of age can use featural differences and similarities to reason about the number of objects involved in an occlusion event (Wilcox & Baillargeon, 1998a,b) and build on these findings by revealing the type of featural information to which infants are most sensitive. In addition, these results raise interesting questions about the hierarchy of features that infants spontaneously attend to and how this hierarchy evolves during development. The remainder of the Conclusion is dedicated to addressing these two issues.

25.1. Changing sensitivity to surface features

The present data provide the first evidence, obtained with an event-monitoring task, that infants use form features before surface features to individuate objects in occlusion events, and add to existing research that suggests that surface features may play a unique role in infants' object representations (Leslie et al., 1998). The present results also document infants' changing sensitivity to two surface features, pattern and color, during the first year of life and suggest that infants' ability to use surface features to individuate objects is not an all-or-none ability that emerges at once, but evolves gradually over time. This is manifested in two ways. First, infants evidence the ability to use some surface features before others. As revealed in Experiments 3 and 4, infants draw on pattern information long before they attend to color information when individuating objects in occlusion events. Second, infants may have the ability to use a surface feature before they do so spontaneously in occlusion situations. For example, in the present experiments, infants first evidenced the ability to use color at 11.5 months (remember that at 7.5 and 9.5 months they failed). However, preliminary results from experiments conducted by Chapa and Wilcox

(1998) suggest that 9.5-month-olds also demonstrate this ability if the importance of color information is highlighted. Together, these results suggest that when infants first recognize that a surface feature, such as color, can signal the presence of distinct objects, their ability to use this knowledge is fragile, and apparent only under limited conditions. Some time passes before infants succeed at drawing on this knowledge in less supportive contexts.

If this hypothesis is correct, a similar developmental trend should be seen with infants' use of pattern information. For example, the negative results obtained in Experiment 3A, along with data from object segregation studies (Craton et al., 1998; Needham, 1998b), suggest that 4- and 4.5-month-old infants lack the knowledge that pattern can be used to reason about individuals. In addition, as demonstrated in Experiment 3B, infants first evidence the ability to spontaneously use pattern around 7.5 months. The current hypothesis predicts that sometime between 4.5 and 7.5 months of age infants will evidence the ability to use pattern if given a more supportive experimental context; for example, if the functional value of attending to pattern information is emphasized. We are currently testing this hypothesis and the preliminary results are encouraging.

25.2. Processing biases and mechanisms for change

The preceding discussion raises two important questions. Why are young infants more sensitive to form features when tracing the identity of objects? And, what leads infants to eventually attend to surface features?

One possibility is that the present results reflect infants' bias to attend to form features when reasoning about occlusion events. There is evidence that when viewing physical events infants classify the events before them into broad categories, such as occlusion, containment, collision, or support (Baillargeon, 1995, 1998; Baillargeon, Kotovsky & Needham, 1995; see also Wilcox & Baillargeon, 1998a). Within event categories, infants first form a preliminary all-or-none concept that captures the essence of the category, and then gradually identify variables that are important to reasoning about the event. Since there are many variables, or aspects, of an event that infants could attend to, young infants tend to focus on variables that: (a) are most relevant to predicting the outcome of the event; and (b) result in the most accurate predictions most of the time. Over time, infants incorporate more varied sources of information into their event categories, allowing for more rich and complex event representations. This results in more accurate predictions across a wider variety of circumstances.

One possible interpretation of the present results, then, is that in the case of occlusion events infants identify shape and size, first, as relevant variables. Indeed, when reasoning about occlusion events, two of the most important factors to consider are shape and size. The shape and size of an object, relative to those of an occluder, determine whether the object can be fully or only partially occluded. In contrast, the pattern and color of an object often has little predictive value. With experience, however, infants may come to realize that pattern and color information can sometimes be useful when reasoning about occlusion events. This experience would lead infants to identify pattern and color as important variables, and then use this information to make judgements about the number of objects present in an occlusion event.

It is also possible that the present results reflect a more general bias to attend to form over surface features when reasoning about physical events. In most physical situations, form features are more important than surface features. For example, in containment events, the size and shape of an object relative to those of a container determine whether the object can fit into the container; in support events, the dimensions and placement of an object relative to a supporting surface determine whether the object will remain supported or fall to the ground; and in collision events, the size of a moving object determines how far a stationary object will be displaced upon contact (Baillargeon, 1995, 1998; Baillargeon et al., 1995, Aguiar & Baillargeon, 1998; Kotovsky & Baillargeon, 1998). Rarely are surface features crucial to making predictions about the outcome of such events and, in turn, infants assign them little importance (Kotovsky & Baillargeon, 1998). This hypothesis predicts that, although the age at which infants first recognize pattern and color information as relevant to a physical situation may vary across event categories (Baillargeon, 1995, 1998; Baillargeon et al., 1995), within each event category infants would first identify form, then surface, features as important.

Even once infants identify surface features as relevant, however, they appear to treat them somewhat differently than form features. For example, there is evidence that as soon as infants identify a form feature, such as height, as important to reasoning about a physical situation, they consistently bring this knowledge to bear (Baillargeon, 1995, 1998; Baillargeon et al., 1995). Infants may become more adept at representing and reasoning about exact quantities (i.e. older infants are better at judging the precise height of an object behind an occluder); however, they do not waiver in their use of an identified variable in like situations. In contrast, the present results, along with those of Chapa and Wilcox (1998), suggest that infants are less reliable in their use of surface features. Infants may identify a surface feature, such as color, as important to reasoning about occlusion events, yet use that feature only under limited conditions (i.e. in more supportive contexts).

If processing biases are responsible for infants' differential responding to shape, size, pattern, and color information, where do they originate? Why are infants slow to identify surface features as important to reasoning about objects in occlusion events and why, once identified, do infants fail to use surface features consistently? One source of bias, alluded to above, is experiential: everyday life may not provide infants with many opportunities to learn that surface features can be used to reason about objects in occlusion events. According to Baillargeon and her colleagues (Baillargeon, 1995, 1998; Baillargeon et al., 1995), infants identify variables through data, or information, obtained from experience with objects, and their interactions, in the physical world. What appears to be particularly important is exposure to contrastive evidence: infants observe that one outcome occurs when a condition is met, and that a different outcome occurs when that condition is *not* met (Baillargeon, 1998; Aguiar & Baillargeon, 1999). It is conceivable that young infants are not exposed to sufficient contrastive evidence within the context of occlusion events. For example, infants may seldom observe occlusion events in which: (a) the objects seen to each side of an occluder either share, or do not share, the same surface features; and (b) a judgment about the number of objects present can *only* be made based on surface features. Without such evidence, it would be difficult for infants to identify surface features as important. Even once identified, infants may have few opportunities to use, and to test, this new knowledge. If surface features are indeed a less reliable source of information than form features (e.g. see below), the opportunity to experiment with this new knowledge might be necessary before infants would be disposed to use it spontaneously.

There may also be other factors that contribute to infants' differential responding to form and surface features. For example, it is possible that the developmental sequence observed in the present experiments reflects, to some extent, the nature of the developing visual system. Initially, infants may have difficulty getting good pattern and color information because of their limited visual capabilities. In addition, infants may view object form as more stable across viewing conditions than surface characteristics. Perception research indicates that infants experience size constancy at birth – infants are capable of extracting the real size of objects even when the retinal size changes (Granrud, 1987; Slater, Mattock & Brown, 1990). Infants also experience shape constancy at birth, at least in some situations (Slater & Morison, 1985; see also Kellman, 1984; Kellman & Short, 1987; Yonas, Aterberry & Granrud, 1987). In contrast, infants first demonstrate color constancy around 4–5 months of age, and then only under limited conditions (Dannemiller & Hanko, 1987; Dannemiller, 1989). Finally, because form features are amodal – they can be experienced visually, orally, or haptically – they may be more salient to young infants. Although perceptual factors, like those listed here, cannot fully account for the present results – clearly infants detect and respond to pattern and color differences before they use them to individuate objects – they may help explain why infants favor form over surface features when reasoning about occlusion events.

Another contributing factor may be the way that infants process and store object information within the context of physical events. Infants' representations of physical events, such as occlusion, containment, or collision, may initially include only information that specifies spatial, temporal, or mechanical relations (see Kotovsky & Baillargeon, 1998). Because form features are spatial in nature, they are included in these early representations, whereas surface features are not. That is not to say that infants do not encode pattern and color information. The fact that infants demonstrate recognition memory for stimuli with these attributes indicates that they do (Olsen & Sherman, 1983; Rovee-Collier, 1990). However, this information is not readily available when the physical reasoning system is engaged. As infants become more practiced at reasoning about physical events, and their representations become more elaborate and detailed, they may attempt to integrate surface features into their event representations. However, until infants become proficient at doing this, they evidence a limited capacity to draw on pattern and color features when reasoning about occluded objects.

25.3. Evidence from the neurosciences

The preceding discussion illustrates the importance of information processing biases to physical reasoning abilities. Examination of recent research in the neurosciences may shed light on the nature and organization of the visual information processing system. There is evidence that the visual system is divided into two main pathways that are neuroanatomically and functionally distinct (Livingstone & Hubel, 1987; 1988; De Yoe & Van Essen, 1988; Desimone & Ungerleider, 1989; Van Essen, Felleman, De Yoe, Olavarria & Knierim, 1990; Ungerleider & Mishkin, 1982; see also Goodale & Milner, 1992). One pathway originates from the *parvocellular* layers of the lateral geniculate nucleus (LGN) and projects from the visual cortex to the temporal cortex. The other pathway originates from the *magnocellular* layers of the LGN and projects from the visual cortex to the parietal lobe. The parvocellular system is important for the analysis of form, pattern, and color information, whereas the magnocellular pathway is important for the analysis of motion, depth, and location information. However, there is reason to believe that both the parvocellular and magnocellular system are involved in shape analysis: whereas the former extracts shape from contour the latter extracts structure from motion (Livingstone & Hubel, 1987, 1988; De Yoe & Van Essen, 1988). In contrast, only the parvocellular system is sensitive to color.

Many researchers believe that the organization of these two systems can be best characterized by two general principles. First, although traditionally the systems have been described as parallel concurrent streams of processing, they may not be as functionally distinct as originally thought (Desimone, Schein, Moran & Urgerleidir, 1985; De Yoe & Van Essen, 1988; Desimone & Ungerleider, 1989). In fact, in their mature state, the two systems may interact quite extensively, especially within the higher cortical areas. Second, each stream of processing is organized hierarchically, such that representations become more complex and integrated at successive stages. In addition, higher-order streams project back to lower-order ones, allowing for 'top-down' aspects of visual processing (Desimone & Ungerleider, 1989).

Although what is known about the maturation of these two systems is limited, there is some evidence that the two pathways mature at different rates. Based on neuroanatomical and behavior data in humans, Johnson (1990) proposed that the magnocellular system becomes functionally mature around 2 months of age, whereas the parvocellular system becomes functionally mature sometime between 3 and 6 months. It is important to point out, however, that the cortical areas involved are not fully mature at this time, especially the higher cortical areas, but continue to develop well past the infancy period (Conel, 1939-1965).

Together, these findings suggest neural mechanisms for early processing biases. For example, early maturation of the magnocellular system may facilitate young infants' use of shape and size information (i.e. assuming that the infants in the present experiments extracted object form from motion cues), whereas infants' later success at using pattern and color features may be mediated by the later developing parvocellular system. Since the magnocellular system is maturationally more advanced, it remains the dominant processing system during the first year of life. (An alternative hypothesis is that the subdivisions of the parvocellular system important for the analysis of shape/size, pattern, and color (e.g. see Gulyas & Roland, 1991) mature at different rates.) In addition, changing sensitivity to surface features may reflect maturation of higher cortical areas. For example, the maturation of 'top-down' connections in the parvocellular system provides a mechanism whereby infants' experience with color information in one situation could increase their sensitivity to color in another (Chapa & Wilcox, 1998).

Although the above account is quite speculative, data from the neurosciences are consistent with infants' differential use of shape, size, pattern, and color information. An attempt to integrate the two literatures may prove quite fruitful: behavioral data can provide a direction for future research in the neurosciences, whereas neuroanatomical and neurobiological data may suggest mechanisms for behavioral change.

25.4. Final comments

The present results build on existing research by providing converging evidence that, with an event-monitoring task, young infants demonstrate the ability to use featural information to individuate objects in occlusion events (Wilcox & Baillargeon, 1998a, b), and by revealing the type of featural information to which infants are most sensitive. More importantly, however, the present research sheds light on how infants go about building representations of occlusion events, the nature and content of infants' event representations, and how these representations change during development. Clearly, infants' representations of occlusion events are not static, but become more rich and diverse over time. How this happens depends on a complex set of experiential and maturational factors. The charge of future research will be to detail exactly how and why these changes occur.

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