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PAPER

Object individuation and event mapping: developmental changes in infants' use of featural information

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Abstract

The present research examined the development of 4.5- to 7.5-month-old infants' ability to map different-features occlusion events using a simplified event-mapping task. In this task, infants saw a different-features (i.e. egg-column) event followed by a display containing either one object or two objects. Experiments 1 and 2 assessed infants' ability to judge whether the egg-column event was consistent with a subsequent one-column display. Experiments 3 and 4 examined infants' ability to judge whether the objects seen in the egg-column event and those seen in a subsequent display were consistent in their featural composition. At 7.5 and 5.5 months, but not at 4.5 months, the infants successfully mapped the egg-column event onto the one-column display. However, the 7.5- and 5.5-month-olds differed in whether they mapped the featural properties of those objects. Whereas the 7.5-month-olds responded as if they expected to see two specific objects, an egg and a column, in the final display the 5.5-month-olds responded as if they simply expected to see 'two objects'. Additional results revealed, however, that when spatiotemporal information specified the presence of two objects, 5.5-month-olds succeeded at tagging the objects as being featurally distinct, although they still failed to attach more specific information about what those differences were. Reasons for why the younger infants had difficulty integrating featural information into their object representations were discussed.

In the world around them, infants routinely observe occlusion events: a toy train disappears into a tunnel and emerges at the other side, a rattle slides under a blanket and is next seen at nap time; dishes are placed into the sink and then removed. One problem that occlusion events present is that of object individuation: keeping track of objects over spatiotemporally distinct presentations. Do infants view each perceptual encounter with an object as a unique individual or are successive presentations integrated and, based on some criteria, viewed as belonging to the same object? Recently, a great deal of attention has been given to infants' ability to use featural information to individuate objects in occlusion events (e.g. Aguiar & Baillargeon, in press; Leslie, Xu, Tremoulet & Scholl, 1998; Spelke, Kestenbaum, Simons & Wein, 1995; Wilcox, 1999b; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Schweinle, 2001; Xu & Carey, 1996). Many of these experiments have revealed that even young infants draw on featural similarities and differences to reason about the number of objects involved in an event (Aguiar & Baillargeon, in press; Wilcox, 1999b; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Schweinle, 2001; see also Wilcox, Schweinle & Chapa, in press, for a review).

To illustrate, in one experiment (Wilcox & Baillargeon, 1998b) 4.5- and 7.5-month-olds saw either a ball-box or a ball-ball test event. In the *ball-box* event, a green ball and a red box emerged successively, and repeatedly, to opposite sides of a screen. In the *ball-ball* event a green ball was seen to both sides of the screen. Infants saw the ball-box or ball-ball test event with either a narrow or a wide 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 alone). The ball-box infants looked reliably longer at the narrow-screen event, as if they had used the featural differences between the ball and the box to conclude that two distinct objects were involved in the ball-box event, and correctly judged that both objects could fit behind the wide, but not the narrow, screen. In contrast, the ball-ball infants looked about equally at

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the narrow- and wide-screen events, as if they had concluded that the ball-ball event involved a single object, and recognized that the ball could fit behind either screen. Converging evidence for this conclusion has been obtained by Wilcox and her colleagues (Wilcox, 1999b; Wilcox & Baillargeon, 1998a; Wilcox & Chapa, 2001) in a number of experiments using variations of the narrow-screen procedure (see Xu & Carey, 2000, however, for an alternative interpretation of the narrow-screen results).

Object individuation and the problem of event mapping

In a different context, however, infants younger than 11.5 to 12 months fail to demonstrate their ability to use featural information to individuate objects (Leslie *et al.*, 1998; Wilcox & Baillargeon, 1998a; Xu & Carey, 1996). This is illustrated by a recent experiment conducted by Wilcox and Baillargeon (1998a). Using an experimental method patterned after that of Xu and Carey (1996), 9.5- and 11.5-month-old infants were presented with the ball-box or ball-ball test event described above with one important difference: after seeing the ball and box successively appear twice to each side of the screen, the ball returned behind the screen and the screen was then lowered. In the final phase of the test event, infants saw a display that contained a single ball sitting on the platform. The 11.5-month-olds in the ball-box condition looked reliably longer at the final one-ball display than the infants in the ball-ball condition. These and control results suggested that the infants had: (a) concluded that the ball-box event involved two objects and the ball-ball event involved one object; (b) compared the initial ball-box or ball-ball event to the one ball before them; and (c) found the ball-box event inconsistent with the one-ball display. In contrast, the 9.5-month-olds in the two conditions looked about equally at the one-ball display, as if they had failed to detect the discrepancy between the initial ball-box event and the one ball before them. These results are consistent with those obtained by Xu and Carey (1996), who reported that 12-month-olds, but not 10-month-olds, succeeded in a two-phase task.

Why did the 4.5-month-olds succeed in the narrow-screen experiment, yet the 9.5-month-olds failed in the two-phase experiment? We believe that the answer to this question lies in an analysis of the processing demands associated with each task (see Wilcox & Baillargeon, 1998a for a fuller account). To succeed in the narrow-screen task, the infants needed to draw a conclusion about the number of objects involved in the test event, and then judge whether the ball and box together, or ball alone, could be fully occluded behind the screen. In other words, the infants simply had to monitor the internal consistency of a single event, an occlusion event, as it played out before them. To succeed in the two-phase task, the infants also had to interpret the ball-box or ball-ball event. In addition, however, the infants had to compare the ball-box or ball-ball event seen in the initial phase of the test trial to the one ball seen in the final phase. That is, the infants needed to map their representation of one event, an occlusion situation, onto that of a second event, a no-occlusion situation, and judge whether the two were consistent.

What we are suggesting, then, is that the infants viewed the initial and final phases of the test trial as two separate events, rather than as one continuous event. On what basis might infants segregate events? There is evidence that infants categorize physical events based on the spatial and mechanical relations between objects (Baillargeon, 1995, 1998), and then re-categorize events when these relations change (Wilcox & Chapa, in press; Hespos, 2000). In the present experiments, the physical category 'occlusion' was changed to one of 'no-occlusion' when the screen was removed.[1] (According to Baillargeon (1995, 1998), event categorization is crucial to infants' learning about the physical world; infants interpret what they observe, predict outcomes and gather information all in terms of selected categories.) Furthermore, it is the process of re-categorization that leads infants to set up, or initiate, new event representations. In order to make sense of the world as it unfolds before them, infants must compare their representations of these independent situations. It is the process of linking up one event representation to another that causes infants difficulty.

In general, tasks that require infants to map one event representation onto another, or event-mapping tasks, are more difficult than tasks that require infants to monitor a single ongoing event, or event-monitoring tasks (see Wilcox *et al.*, in press, for a review). This is not to say,

[1] Although 'no-occlusion' does not seem to have the same status as other more common sense categories (e.g. occlusion, support, containment), there is evidence that infants view occlusion and no-occlusion portions of an event as belonging to distinct categories (Chapa & Wilcox, 2000). This might leave one wondering why other experiments conducted with young infants, in which an occluder was introduced and then removed, have produced positive results (e.g. Baillargeon, Graber, DeVos & Black, 1990; Spelke, Breinlinger, Macomber & Jacobson, 1992; Wilcox, Nadel & Rosser, 1996; Wynn, 1992). In all of these experiments, infants were given unambiguous spatiotemporal information as to the number of objects present. When infants are shown, explicitly, how many objects are present in an event, rather than having to draw inferences about the existence of multiple objects, their event representations are more clear. Having a clear event representation facilitates mapping performance.

however, that young infants cannot succeed with event-mapping tasks. Recall that in the initial phase of the ball-box test event described above, the objects were seen twice to each side of the screen, and reversed direction each time before returning behind the screen. The repeating nature of the event, which included multiple object reversals and occluded trajectories, resulted in a relatively lengthy and complex event. There is evidence that if the initial event is made extremely simple and brief, so as to reduce the burden associated with retrieving and scanning the event, mapping performance improves. For example, Wilcox and Baillargeon (1998a) presented 9-month-olds with a very simple event involving the box and/or the ball. In the initial phase of the test event, a box (box-ball condition) or a ball (ball-ball condition) disappeared behind the left edge of a wide screen and a ball appeared at the right edge; the screen was then lowered. In the final phase of the test event, infants saw only the ball to the right of the screen (the area behind the screen was empty). The box-ball infants looked reliably longer during the final phase of the test event, as if they recognized that the box-ball sequence, seen in the initial phase of the test event, was inconsistent with the one ball before them. When the objects followed a single trajectory, left to right across the platform, the infants were able to successfully map a different-features event onto a one-object display.

Object individuation and object identification

The individuation results presented above shed light on how infants go about establishing and using their representations of distinct objects. What has been left open to speculation, however, is how infants represent, in short-term memory, the physical entities that they individuate. This problem is best understood within the context of the distinction, recently made by Leslie and his colleagues (Leslie *et al.*, 1998; see also Kaldy & Leslie, 2001; Scholl & Leslie, 1999; Tremoulet, Leslie & Hall, 2001), between object individuation and object identification. Individuation-by-feature refers to the process by which featural differences are used to draw conclusions about how many objects are present in an event. That is, a change in featural information signals the presence of a new object. In contrast, identification-by-feature is the process of identifying an object, that was seen previously, using featural information. This requires that one attach, or bind, to individuals their featural characteristics. Most importantly, it is possible for infants to individuate objects on the basis of featural differences, yet fail to identify those same objects by their featural properties. To illustrate, consider the two-phase task used by Wilcox and Baillargeon (1998a). There are two different ways that the 9-month-olds could have represented the box-ball event that would have led them to respond with increased looking to the one-ball display. One possibility is that the infants represented the box-ball event as involving two objects, one that moved to the left of the screen and another that moved to the right. When the screen was lowered, the infants were surprised to see a single object on the platform. According to this view, the infants represented the number of objects that they had seen in the occlusion event and recognized that the final display was inconsistent with this number, without calling forth the exact featural composition of each object. Alternatively, the infants may have represented the box-ball event as involving two specific objects, a box to the left of the screen and a ball to the right. When the screen was lowered, the infants were surprised to see only the ball on the platform. According to this view, the infants successfully represented the number and the featural properties of the objects, and were surprised when the final display failed to contain the box. Since either one of these representations – ‘two objects’ or ‘a box and a ball’ – would have led the infants to judge the final one-ball display as unexpected, the event-mapping results, as they stand, are not sufficient to distinguish between these two possibilities.

The present research

The purpose of the present research was twofold. The first was to identify the age at which infants first evidence success at mapping a different-features event when the objects follow a single uncomplicated trajectory. If the mapping of different-features events is made substantially easier when the objects' trajectories are simplified, then one would expect infants younger than 9 months to succeed on this task. The second was to examine whether infants would be able to identify, based on featural information, the objects that they had individuated. Four experiments were conducted with 7.5-, 5.5- and 4.5-month-olds using a simplified event-mapping task patterned after Wilcox and Baillargeon (1998a). The main findings were as follows. The 7.5- and 5.5-month-olds, but not the 4.5-month-olds, correctly judged that a different-features occlusion event was inconsistent with a subsequent one-object display (Experiments 1 and 2). However, there were important developmental changes in the way that the infants represented the different-features event. Whereas the 7.5-month-olds successfully retrieved information about the featural properties of the objects involved, the 5.5-month-olds were unable to identify the objects based on their featural characteristics (Experiments 3 and 4). Additional results revealed, however, that under some circumstances the 5.5-month-olds tagged, or marked, the objects as being featurally distinct, even though they still failed to identify what those differences were.

Experiment 1

In Experiment 1, 7.5-month-olds were assigned to one of two conditions: egg-column or column-column. Infants in the *egg-column* condition saw a test event in which an egg disappeared behind the left edge of a wide screen and a column appeared at the right edge. The screen was then lowered to reveal only the column to the right of the screen. Infants in the *column-column* condition saw a similar event, except that in the initial phase of the event a column was seen to both sides of the screen. If infants use the featural information to conclude that the egg-column event involves two objects and the column-column event involves one object, and can successfully map their representation of the egg-column or column-column event onto the one-column display, then the infants in the egg-column condition should look reliably longer at the one-column display.

Method

Participants

Participants were 14 healthy full-term 7.5-month-old infants, 7 male and 7 female (M = 7 months, 15 days; range = 7 months, 3 days to 8 months, 7 days). Five additional infants were eliminated from the experiment because of procedural problems (four because the infant grabbed the lowered screen and one because a sibling distracted the infant during the test session). Seven infants were randomly assigned to the egg-column (M = 7 months, 17 days) and the column-column (M = 7 months, 14 days) condition.

In this and all subsequent experiments, the infants' names were obtained from birth announcements in the local newspaper. Parents were contacted by letters and follow-up phone calls. Parents were offered reimbursement for their travel expenses, but were not compensated for their participation.

Apparatus

The apparatus consisted of a wooden cubicle 213 cm high × 105 cm wide × 43.5 cm deep. The infant sat facing an opening 51 cm high × 93 cm wide in the front wall of the apparatus. The floor of the apparatus was covered

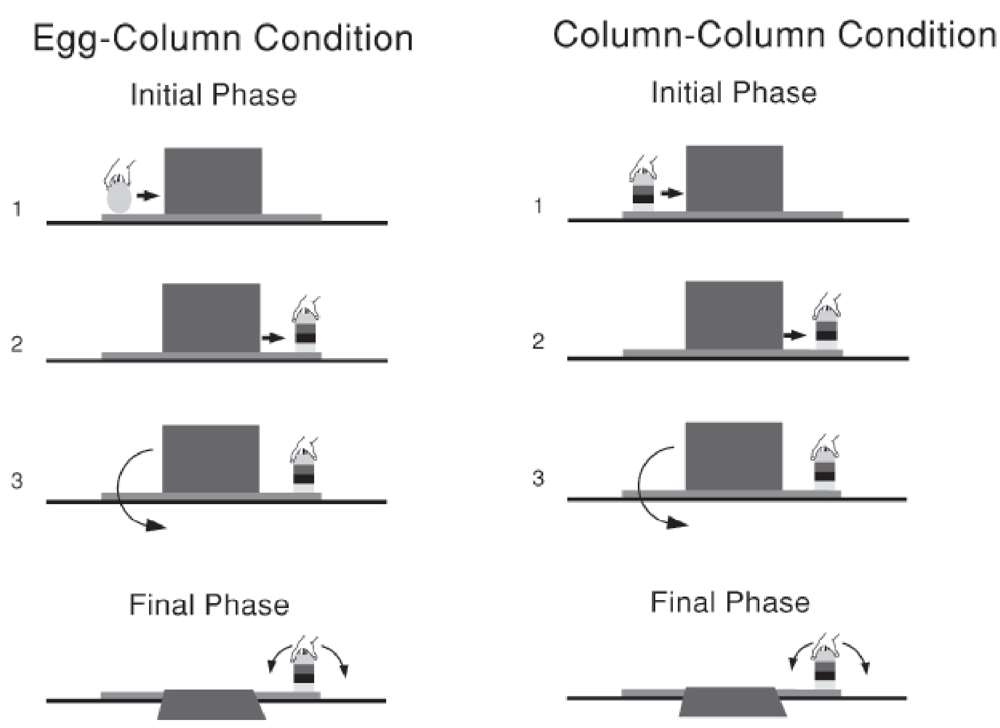

Figure 1 *Schematic drawing of the test events in the egg-column and column-column conditions of Experiments 1 and 2.*

with cream colored contact paper and the side walls were painted cream; the back wall was covered with wood-grain patterned contact paper. A cream colored platform 1.5 cm tall × 59.5 cm wide × 19 cm deep lay flush against the back wall, centered between the left and right walls; a 12 cm wide piece of light blue flannel lay lengthwise down the center of the platform. The experimenter's hand moved the objects through a slit 7.5 cm high × 80 cm long, located 12 cm above the apparatus floor. A strip of white fringe 14 cm high × 92 cm long helped conceal the slit. Objects could be moved in or out of the apparatus through an opening, 10 cm high × 9 cm wide, that was located behind the screen. When the screen was lowered, the opening was concealed by a removable door.

The screen used in the familiarization and test events was 31 cm wide × 36 cm high and was mounted on two metal clips positioned 11.75 cm to either side of the center of the platform. The clips were attached to a wooden dowel 1 cm in diameter that lay on the apparatus floor directly in front of the platform. The left end of the dowel exited the apparatus through a small hole in the left wall and was secured in place with a metal pin. The right end of the dowel exited the apparatus through a small hole in the right wall. By rotating the dowel's right end (out of the infants' view), an experimenter could lower the screen to the apparatus floor. The screen was made of cardboard and covered with green contact paper.

The infants in the egg-column condition saw two test objects: an egg and a column. The egg was 7 cm in diameter at its widest point and 10.5 cm tall, made of Styrofoam, painted yellow and adorned with small colored stars. The column was 7 cm wide, 7 cm deep and 12 cm tall, made of Styrofoam, and covered with red and white checkered cloth. A second identical column was used in the column-column condition. The objects were affixed to a clear Plexiglas base that was 0.25 cm thick and 7.5 cm wide and 3 cm deep for the egg and 7 cm wide and 6 cm deep for the column. The Plexiglas base, which was hidden from the infants' view by a 1.25 cm high lip attached to the front of the platform, allowed for smooth and silent movement of the objects along the felt-covered platform.

Events

Three experimenters worked together to produce the pretest displays and test events. Two experimenters wore a white glove on their right hand and manipulated the objects; a third operated the screen. The numbers in parentheses indicate the time taken to produce the actions described. A metronome ticked softly once per second to help the experimenters adhere to the events' scripts.

Egg-column condition

Pretest displays

In the first pretest display, the first experimenter's right hand held the egg to the left of the screen and tilted it gently to the left and to the right (once to each side per second) until the end of the trial. In the second display, the hand held the column to the right of the screen and tilted it gently until the trial ended. The hand held each object from the top.

Test event

At the start of the test event, the first experimenter tilted the egg gently to the left and right, its center about 5.75 cm from the left edge of the platform. The screen stood upright at the center of the platform; the column sat behind the right side of the screen. After the computer signaled that the infant had looked at the egg for 2 cumulative seconds, the *initial phase* of the test event began. The hand moved the egg behind the screen; the first experimenter then surreptitiously removed the egg from the apparatus through a hidden opening in the back wall (2 s). Next, the second experimenter's right hand moved the column from behind the screen to the right end of the platform (2 s) (the two experimenters had similar sized hands covered in identical white gloves). The hand then began tilting the column, as before (2 s). Finally, the third experimenter lowered the screen to the apparatus floor (1 s), marking the end of the initial phase. During the *final phase*, the infants saw the empty area behind the screen and the column to the right of the screen, being gently tilted by the hand.[2]

[2] One might be concerned that the second experimenter, who held the object during the final phase of the test event, produced the event in a way that would bias the results. Several precautions were taken to ensure that the final phase of the test was presented uniformly across conditions in this and subsequent experiments. First, although the second experimenter was not blind to the experimental condition to which each infant was assigned, they were blind to our experimental hypotheses. Five individuals worked as the second experimenter. Of the 133 infants tested in Experiments 1–4, the distribution was as follows: Experimenter 1, $n = 66$; Experimenter 2, $n = 51$; Experimenter 3, $n = 6$; Experimenter 4, $n = 6$; Experimenter 5, $n = 4$. The proportion of infants tested by each of the experimenters was approximately the same in each experiment (and was similar to the overall proportions). Hence, even if one of the experimenters had her *own* hypotheses, and unintentionally acted on them, she alone could not be responsible for the pattern of results obtained here. Second, the physical movements of the second experimenter were constrained by the physical make-up of the apparatus. The narrow slit in the back wall of the apparatus, through which the arm moved, allowed for little, if any, vertical movement of the forearm. Third, a video camera was placed directly behind, and slightly above, the parent's head and the event was projected onto

Column-column condition

The pretest displays and test event were identical to those in the egg-column condition with one exception: a second, identical column was substituted for the egg.

Procedure

The infant sat on a parent's lap centered in front of the apparatus. The infant's head was approximately 80 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 test events.

Each infant participated in a two-step procedure that consisted of a pretest period and a test period. During the *pretest* period, the infants saw the pretest displays appropriate for their condition on two successive trials. The pretest trials ended when the infant either (a) looked away for 2 consecutive seconds after having looked for at least 5 cumulative seconds or (b) looked for 30 cumulative seconds without looking away for 2 consecutive seconds. During the *test* phase, the infants saw the test event appropriate for their condition on two successive trials. Looking time during the initial and final phase of each trial was monitored separately. The final phase of each trial ended when the infant either (a) looked away for 2 consecutive seconds after having looked for at least 4 cumulative seconds or (b) looked for 60 cumulative seconds without looking away for 2 consecutive seconds.

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.[3] 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 were used to determine when a trial had ended. 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. Inter-observer agreement during the final phase of each test trial was calculated for each 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. Inter-observer agreement was measured for 11 of the infants (for 3 of the infants, data from only one observer were available) and agreement averaged 95% per test trial per infant.

Results

Preliminary analyses

Preliminary analyses were conducted for each of the experiments reported herein to explore whether males and females responded differently to the test events. These analyses failed to reveal any reliable sex differences. Hence, in this and the following experiments the data were collapsed across sex. However, because of the small number of infants in each cell for each analysis, these results need to be interpreted with caution.

Pretest-display trials

The infants' looking times during the pretest-display trials were analyzed by means of a mixed-model ANOVA with trial (first or second) as a within-subjects factor and condition (egg-column or column-column) as a between-subjects factor. The main effect of trial, $F(1, 12) = 0.22$, and of condition, $F(1, 12) = 3.62$, were not significant, $p > 0.05$. The trial × condition interaction was marginally significant, $F(1, 12) = 4.39$, $p = 0.06$. The infants in the egg-column condition tended to look longer during the second ($M = 28.9$ s, SD = 1.4) than the first ($M = 24.8$ s, SD = 6.2) pretest trial, whereas the infants in the column-column condition tended to look slightly shorter during the second ($M = 17.9$ s, SD = 10.3) than the first ($M = 24.3$ s, SD = 8.1) pretest trial. This trend is not surprising, since the infants in the egg-column condition saw a new object, and the infants in the column-column condition saw the same object, in the second pretest trial.

Test trials

The infants' looking times during the final phase of the two test trials (Figure 2) were averaged and analyzed by means of a one-way ANOVA with condition (egg-column or column-column) as a between-subjects factor. The main effect of condition was significant, $F(1, 12) = 4.93$, $p < 0.05$, indicating that the infants in the

a monitor that could be seen by both the experimenters (but not the observers). The first experimenter was trained to detect and record any deviation in procedure during the final phase of the event (the second experimenter monitored the initial phase of the event). All of the infants included in the sample met the designated procedural criteria.

[3] The infants in Experiments 1 and 2 were all presented with test events in which a column or an egg and a column appeared to either side of a screen. For the 56 infants tested, the primary observer was asked at the end of the test session whether the infants had seen the same object or different objects on the two sides of the screen. The primary observer guessed correctly for only 29 of the 56 infants, a performance not significantly different from chance (cumulative binomial, $p > 0.05$).

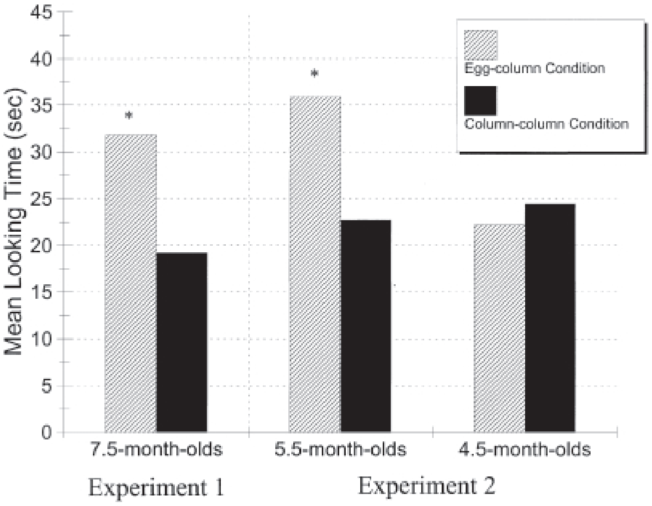

Figure 2 *Mean looking times of the infants in Experiments 1 and 2 during the final phase of the test event.*

egg-column condition (M = 31.8 s, SD = 13.0) looked reliably longer than those in the column-column condition (M = 19.2 s, SD = 7.7).[4]

Discussion

The infants in the egg-column condition looked reliably longer at the final display than those in the column-column condition. These results suggest that the infants in the egg-column condition used the featural differences between the objects seen to each side of the screen to conclude that two objects were involved in the initial event and found their representation of the egg-column event inconsistent with the one-column display. In contrast, the infants in the column-column condition used the featural similarities of the objects seen to each side of the screen to conclude that just one object was involved in the column-column event and recognized the column-column event as congruent with the final display. These results suggest that infants younger than 9 months can succeed at mapping different-features events when the objects follow very simple and brief trajectories.

[4] The positive results obtained in Experiment 1 suggest that the infants expected to see two objects when the screen was lowered and found the presence of only the one column inconsistent with this expectation. This interpretation of the data predicts that infants would not find unexpected a display containing two objects (i.e. an egg and a column). Data obtained in a subsequent experiment allow us to test this prediction. In Experiment 3, 7.5-month-olds (control egg-column condition) saw the egg-column event described above with one exception: the final display contained an egg and a column, rather than just the egg. A comparison of the looking times of the infants in Experiment 3 who saw an egg and a column in the final display (M = 18.6 s, SD = 8.0) to those of the infants in Experiment 1 who saw only the column, indicates that the infants looked reliably longer at the one column, $F(1,12) = 5.25$, $p < 0.05$. These results provide converging evidence for the conclusion that the infants in Experiment 1 looked reliably longer at the final display because they expected to see two objects when the screen was lowered and were surprised to see just one.

Experiment 2

The 7.5-month-olds' success in Experiment 1 led us to question whether even younger infants could succeed at mapping a simplified different-features occlusion event. Remember that 4.5-month-olds can correctly *interpret* a different-features occlusion event, as evidenced by their performance on event-monitoring tasks (Wilcox, 1999b; Wilcox & Baillargeon, 1998b). Whether infants as young as 4.5 months can also demonstrate the ability to *map* a different-features occlusion event was the focus of the next experiment. Infants 4.5 and 5.5 months of age were tested using a procedure similar to that of Experiment 1, except that the infants were given more time to view the objects prior to the test trials.

Method

Participants

Participants were 14 4.5-month-olds, 6 male and 8 female (M = 4 months, 16 days; range = 4 months, 1 day to 5 months, 0 days), and 14 5.5-month-olds, 6 male and 8 female (M = 5 months, 18 days; range = 5 months, 6 days to 5 months, 29 days). Two additional infants were eliminated from the experiment, one because of straining (i.e. a bowel movement) and one because the primary observer was unable to determine the direction of the infant's gaze. Seven infants of each age were randomly assigned to the egg-column (M = 4 months, 20 days; M = 5 months, 16 days) and the column-column (M = 4 months, 11 days; M = 5 months, 19 days) condition.

Apparatus

The apparatus and stimuli were identical to those used in Experiment 1.

Events

Egg-column condition

The pretest displays and test event were identical to those in the egg-column condition in Experiment 1 with one exception: infants saw four pretest displays (alternating egg and column) prior to the test trials. This modification, in addition to an increase in the length of the pretest trials (see below), was implemented to ensure that the younger infants had sufficient time to encode the objects prior to the test event (Cornell, 1979; Fagan, 1974, 1977; Rose, Gottfried, Melloy-Carminar & Bridger, 1982).

Column-column condition

The pretest displays and test event were identical to those in the column-column condition in Experiment 1 with one exception: infants saw four pretest displays.

Procedure

The procedure was identical to that of Experiment 1 with one exception: the pretest trials ended when the infant either (a) looked away for 2 consecutive seconds after having looked for at least 5 cumulative seconds or (b) looked for 60 cumulative seconds without looking away for 2 consecutive seconds. Inter-observer agreement during the final phase of the test trial was measured for 23 of the infants and averaged 93%.

Results

Pretest-display trials

To compare the looking times of the infants who saw the column on all four pretest-display trials (column-column condition) to those of the infants who saw the egg and column on alternating trials (egg-column condition), looking times were averaged for pretest trials one and three (first trial pair) and for pretest trials two and four (second trial pair). The infants' mean looking times were analyzed by means of a mixed-model ANOVA with trial pair (first or second) as a within-subjects factor and condition (egg-column or column-column) and age (4.5 months or 5.5 months) as between-subjects factors. The main effect of trial pair, $F(1, 24) = 3.41$, of condition, $F(1, 24) = 0.08$, and of age, $F(1, 24) = 0.63$, were not significant, $p > 0.05$. The two-way interactions were not significant, all Fs < 1.9. However, the trial pair × condition × age interaction was significant, $F(1, 24) = 9.44$, $p < 0.01$. Follow-up analyses indicated that for the 4.5-month-olds, there were no reliable main effects of trial pair or condition, nor a significant interaction between those two factors, all Fs < 1.9 (egg-column condition, trial pair 1, $M = 39.8$ s, SD = 13.8, trial pair 2, $M = 31.6$ s, SD = 9.3; column-column condition, trial pair 1, $M = 38.5$ s, SD = 18.9; trial pair 2, $M = 39.3$ s, SD = 16.3). For the 5.5-month-olds, the main effect of trial pair and of condition were not significant, all Fs < 2.3, but the trial pair × condition interaction was significant, $F(1, 12) = 8.45$, $p < 0.025$. Additional analyses revealed that whereas the looking times of the infants in the egg-column condition did not differ reliably between the two trial pairs (trial pair 1, $M = 41.5$ s, SD = 17.2; trial pair 2, $M = 47.2$ s, SD = 14.0), $F < 1$, the infants in the column-column condition looked reliably longer during the first ($M = 47.0$ s, SD = 16.7) than the second ($M = 29.5$ s, SD = 12.0) trial pair, $F(1, 6) = 43.4$, $p < 0.001$.

One might be concerned that the 5.5- and 4.5-month-olds evidenced reliably different patterns of looking during the pretest-display trials (i.e. the younger infants were less likely to show a decrease in looking across trial pairs) because the younger infants had difficulty encoding the featural properties of the objects. This would have made individuation-by-feature difficult. Although possible, we believe this unlikely, for several reasons. First, if the 4.5-month-olds had difficulty encoding the featural properties of the objects, one would expect their looking times during the pretest-display trials to be at ceiling, or at least higher than those of the 5.5-month-olds, and this was not the case. Second, infant memory research (Cornell, 1979; Fagan, 1974, 1977; Rose *et al.*, 1982) suggests that the infants had more than adequate time to encode the features for subsequent recognition. For example, there is evidence that 3.5-month-olds need only 30 seconds of familiarization time to recognize a visual stimulus when tested immediately (Rose *et al.*, 1982), and that 5- to 6-month-olds need only 10 seconds of familiarization time (Cornell, 1979). The mean looking times of the 4.5-month-olds to the pretest displays was well over 30 seconds and, in fact, all of the 4.5-month-olds accumulated at least 30 seconds looking time to each object. Third, because a familiarization, rather than a habituation, procedure was used we would not necessarily expect to see reliable pretest trial effects. This does not mean, however, that the infants had not sufficiently encoded the features for subsequent recognition.

Test trials

The infants' looking times during the final phase of the two test trials (Figure 2) were averaged and analyzed by means of an ANOVA with condition (egg-column or column-column) and age (4.5 months or 5.5 months) as between-subjects factors. The main effect of condition, $F(1, 24) = 2.29$, and of age, $F(1, 24) = 2.67$, were not significant, $p > 0.05$. However, the condition × age interaction was significant, $F(1, 24) = 4.39$, $p < 0.05$. Planned comparisons indicated that the 5.5-month-olds in the egg-column condition ($M = 35.9$ s, SD = 9.5) looked reliably longer than those in the column-column condition ($M = 22.7$ s, SD = 9.1), $F(1, 14) = 13.04$, $p < 0.01$.

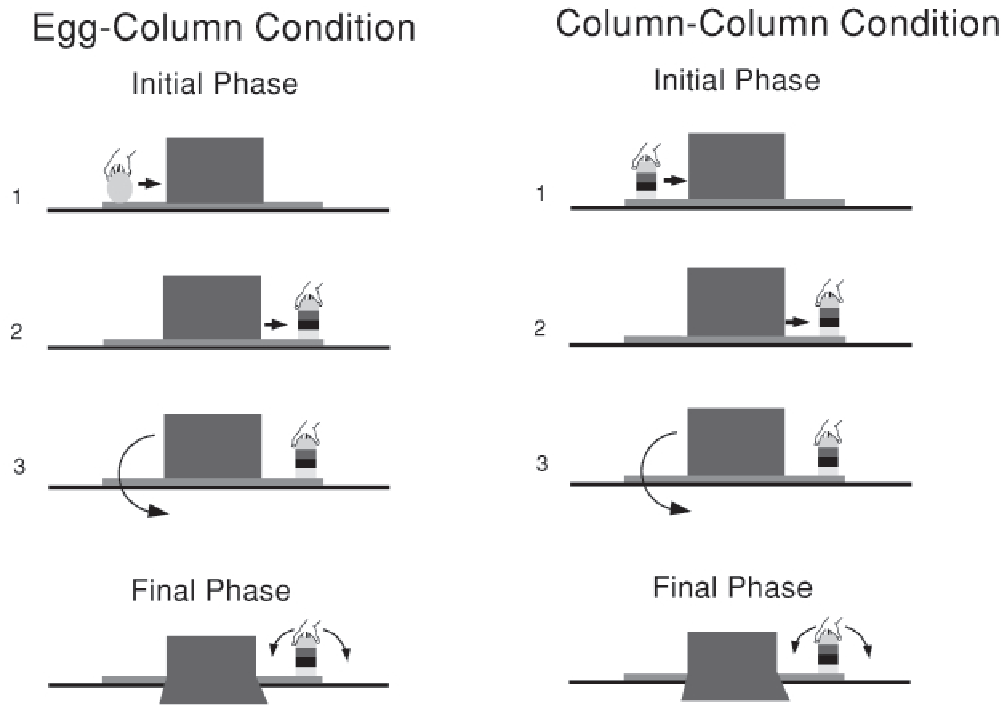

Figure 3 *Schematic drawing of the test events in the control egg-column and control column-column conditions of Experiment 2.*

In contrast, the 4.5-month-olds in the egg-column (M = 22.2 s, SD = 8.1) and the column-column (M = 24.4 s, SD = 11.7) condition looked about equally at the one-column display, $F(1, 14) = 0.34$, $p > 0.05$.[5]

Additional control results

One interpretation of the positive results obtained with the 5.5-month-olds is the one offered for the 7.5-month-olds in Experiment 1: the infants (a) succeeded in retrieving a representation of the initial event they were shown, (b) mapped this representation onto the display presented in the final phase of the event and (c) correctly judged whether a discrepancy existed between the two. It could be objected, however, that there were other, less impressive explanations for these positive results. For example, perhaps the infants found an event in which different objects (i.e. an egg and a column) appeared to each side of the screen more interesting than an event in which the same object (i.e. a column) appeared to each side of the screen. Heightened interest to the egg-column event during the initial phase of the test trial could have inflated looking times to the one-column display during the final phase of the test trial. Alternatively, it is possible that the egg-column infants found the column more novel than the column-column infants. Since the egg-column infants saw the column on only two familiarization trials, and the column-column infants saw the column on four familiarization trials, the egg-column infants had less time to encode the column prior to the test trials.

These explanations seem highly unlikely in light of the negative results obtained with the 4.5-month-olds (unless the younger infants, for some reason, were less intrigued by the egg-column event or were less likely to respond to novelty). Nevertheless, to evaluate these alternative interpretations more thoroughly, 14 5.5-month-olds (6 males, 8 females, M = 5 months, 16 days, range = 5 months, 5 days to 5 months, 27 days) were tested in a control experiment identical to Experiment 2 with one exception (Figure 3): when the screen was lowered, a second, shorter screen (31 cm wide and 24 cm tall) was revealed that hid the central portion of the platform.

[5] The positive results obtained with the 5.5-month-olds suggest that they expected to see two objects when the screen was lowered and found the presence of only one object inconsistent with this expectation. To test this interpretation, the looking times of the infants in the egg-column condition were compared to those of the 5.5-month-olds in the control egg-column condition in Experiment 3, who saw the egg-column event followed by a display containing an egg and a column. This comparison revealed that the infants in Experiment 2 who saw the one-column display looked reliably longer than those in Experiment 3 who saw the egg-and-column display (M = 23.3 s, SD = 9.6), $F(1,12) = 6.04$, $p < 0.05$. These results support the conclusion that the 5.5-month-olds, like the 7.5-month-olds, expected to see two objects following the egg-column event and were surprised to see just one.

If the infants in the experimental egg-column condition looked reliably longer than those in the experimental column-column condition simply because seeing the egg to the left of the screen heightened their response during the final phase of the test event, or because they found the column more novel, then the infants in the control egg-column condition should also look longer than those in the control column-column condition. On the other hand, if the infants in the experimental egg-column condition looked longer because they were puzzled *not* to see the egg when the screen was lowered, then the infants in the control egg-column condition, who could assume that the egg lay hidden behind the shorter screen, would respond in the same manner as the infants in the control column-column condition.

The infants' looking times during the final phase of the test trial were analyzed by means of a one-way ANOVA with condition (control egg-column or control column-column) as a between-subjects factor. The main effect of condition was not significant, $F(1,12) = 0.09$, $p > 0.05$, indicating that there was no reliable difference between the looking times of the infants in the control egg-column (M = 25.7 s, SD = 16.8) and the control column-column (M = 23.5 s, SD = 7.9) conditions. These results suggest that the infants in the experimental egg-column condition evidenced longer looking times during the final phase of the event because they found the presence of a single object unexpected, not because of other, superficial differences between the two events.

One might, however, consider one last alternative hypothesis. Perhaps the infants in the control egg-column and column-column conditions failed to evidence reliably different looking times during the final phase of the event because they were distracted by the presence of the second screen (i.e. seeing the second screen standing behind the lowered screen was such a novel event that infants in both conditions attended to that aspect of the display). Although certainly possible, there is reason to doubt such an explanation. First, if the differential responding of the egg-column and column-column infants was obliterated because of piqued interest to the screen at the center of the platform, one would expect the looking times of the infants in the two control conditions to be higher than those of the infants in the experimental conditions (or at least as high as those in the experimental egg-column condition), and this was not the case. Second, the presence of a screen occluding the center of the platform was perceptually *less* novel than seeing the center of the platform unoccluded. In the pretest-display trials and in the initial phase of the test event a screen occluded the center of the platform, just like it did in the final phase of the test event. The *only* difference between the two screens was that the second screen was slightly shorter, a difference that was perceptible but certainly not intriguing.

Discussion

In Experiment 2, the 4.5-month-olds in the two conditions looked about equally at the one column when the screen was lowered, as if they had failed to map the initial occlusion event onto the final one-column display. In contrast, the 5.5-month-olds in the egg-column condition looked reliably longer at the one-column display. These and control results suggest that the 5.5-month-olds successfully retrieved their representation of the initial occlusion event and judged that the column-column, but not the egg-column, event was consistent with the presence of a single column in the final display. These results extend the positive results obtained with the 7.5-month-olds in Experiment 1 to younger infants and reveal that, when the objects follow very simple and brief trajectories, infants as young as 5.5 months can succeed at mapping different-features occlusion events.

What the results of Experiments 1 and 2 leave open to interpretation, however, is what kind of information the infants were mapping from the occlusion to the no-occlusion situation. The remaining experiments examined more closely the nature of the infants' representation of the egg-column event.

Experiment 3

The purpose of Experiment 3 was to identify why the 7.5-month-olds (Experiment 1) and the 5.5-month-olds (Experiment 2) who saw the egg-column event found the final one-column display unexpected. One possibility is that the infants represented the egg-column event as involving two objects, one that moved to the left of the screen and a second that moved to the right. When the screen was lowered, the infants were surprised to see a single object. Alternatively, the infants may have represented the egg-column event as involving two featurally distinct objects, an egg to the left of the screen and a column to the right. When the screen was lowered, the infants were surprised to see only the column on the platform.

To test these two possibilities, 7.5- and 5.5-month-olds were presented with the egg-column event with one exception (Figure 4): when the screen was lowered, infants saw a display containing either two columns (experimental condition) or an egg and a column (control condition). If infants represented the egg-column event as involving two objects, but failed to recall the

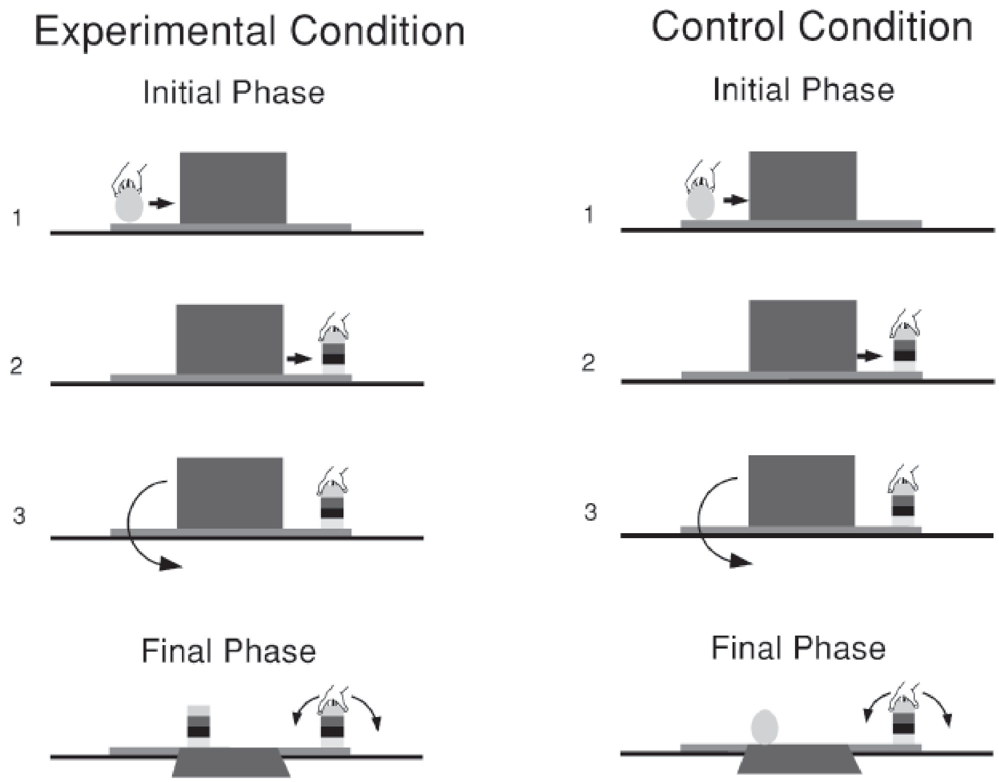

Figure 4 *Schematic drawing of the test events in the experimental and control conditions of Experiment 3.*

featural composition of the objects, then the infants in the experimental and control conditions should look about equally at the final display. In contrast, if the infants retrieved a representation that included two featurally distinct objects, an egg and a column, then the infants in the experimental condition should look longer at the final display than the infants in the control condition.

Method

Participants

Participants were 14 7.5-month-olds, 7 male and 7 female (M = 7 months, 14 days; range = 7 months, 0 days to 8 months, 3 days) and 14 5.5-month-olds, 7 male and 7 female (M = 5 months, 16 days; range = 5 months, 6 days to 6 months, 0 days). Two additional 7.5-month-olds were eliminated from the experiment because of procedural problems (one infant grabbed the screen and another was distracted by a sibling). One additional 5.5-month-old was eliminated from the experiment because the primary observer was unable to determine the direction of the infant's gaze. Seven infants of each age were randomly assigned to the experimental (M = 7 months, 7 days; M = 5 months, 13 days) and the control (M = 7 months, 21 days; M = 5 months, 19 days) egg-column condition.

Apparatus

The apparatus and stimuli were identical to those used in Experiments 1 and 2 with one addition: a second identical column was used in the final display of the experimental condition.

Events

Experimental condition

The pretest displays and test event were identical to those in the egg-column condition of Experiments 1 and 2 with one exception. In the initial phase of the test event, after the experimenter removed the egg from the apparatus, a column was inserted. During the final phase, infants saw one column standing behind the lowered screen and an identical column tilting to the right of the screen. The 7.5-month-olds saw two pretest-display trials whereas the 5.5-month-olds saw four pretest-display trials (alternating egg and column).

Control condition

The pretest displays and test event were identical to those in the experimental condition with one exception. In the initial phase of the test event, the first experimenter surreptitiously removed and then reinserted the egg in the apparatus. This was done to prevent infants and observers from distinguishing between events on the basis of faint noise cues associated with the removal and insertion of objects. During the final phase, infants saw the egg standing behind the lowered screen, in addition to the column tilting to the right of the screen.

Procedure

The 7.5- and 5.5-month-olds were tested using the procedures from Experiments 1 and 2, respectively. The difference between the two procedures was in the pretest-display trials. For the 7.5-month-olds, the pretest trials (infants saw two) ended when the infant either (a) looked away for 2 consecutive seconds after having looked for at least 5 cumulative seconds or (b) looked for 30 cumulative seconds without looking away for 2 consecutive seconds. Inter-observer agreement during the final phase of the test trial was measured for 14 of the infants and averaged 96%. For the 5.5-month-olds, the pretest trials (infants saw four) ended when the infant either (a) looked away for 2 consecutive seconds after having looked for at least 5 cumulative seconds or (b) looked for 60 cumulative seconds without looking away for 2 consecutive seconds. Inter-observer agreement during the final phase of the test trial was measured for 12 of the infants and averaged 93%. The observers were not told, and could not determine, the condition to which each infant was assigned.[6]

Results

Pretest-display trials

Because the 7.5- and 5.5-month-olds saw a different number of pretest trials, and were tested using different trial termination criteria, their pretest and test data are not directly comparable. Hence, separate analyses were conducted for the two age groups.

7.5-month-olds

The infants' looking times during the pretest-display trials were analyzed by means of a mixed-model ANOVA with trial (first or second) as a within-subjects factor and condition (experimental or control) as a between-subjects factor. The main effect of trial and of condition, and the trial × condition interaction, were not significant, all Fs < 1.4, indicating that there were no reliable differences in looking times across the pretest trials for either group (experimental condition, trial 1 $M = 28.4$ s, SD = 4.3, trial 2 $M = 22.6$ s, SD = 9.9; control condition, trial 1 $M = 23.1$ s, SD = 7.3, trial 2 $M = 21.3$ s, SD = 10.2).

5.5-month-olds

The infants' mean looking times for the first trial pair (M of trials 1 and 3) and the second trial pair (M of trials 2 and 4) were analyzed by means of a mixed-model ANOVA with trial pair (first or second) as a within-subjects factor and condition (experimental or control) as a between-subjects factor. The main effect of trial pair was not significant, although it was marginal, $F(1,12) = 4.40$, $p = 0.06$ and the main effect of condition was not significant, $F(1,12) = 2.13$, $p > 0.05$. The trial pair × condition interaction was not significant, $F < 1$. Together, these results suggest that the infants tended to look longer during the first trial pair (experimental condition, $M = 44.0$ s, SD = 9.6; control condition, $M = 34.3$ s, SD = 15.2) than the second trial pair (experimental condition, $M = 33.9$ s, SD = 17.7; control condition, $M = 25.9$ s, SD = 12.2).

Test trials

7.5-month-olds

The infants' looking times during the final phase of the two test trials were averaged (Figure 5) and analyzed by means of a one-way ANOVA. The main effect of condition was significant, $F(1, 12) = 5.34$, $p < 0.05$, indicating that the infants in the experimental condition ($M = 31.4$ s, SD = 12.3) looked reliably longer than those in the control condition ($M = 18.6$ s, SD = 8.0).

5.5-month-olds

The infants' looking times (Figure 5) were analyzed in the same manner as the 7.5-month-olds. The main effect of condition was not significant, $F(1, 12) = 0.01$, $p > 0.05$, indicating that the infants in the experimental ($M = 23.9$ s, SD = 10.9) and control ($M = 23.3$ s, SD = 9.6) conditions did not differ reliably in their mean looking times during the test trials.

[6] The infants in Experiments 3 and 4 were all presented with egg-column test events in which either two columns or an egg and a column were seen in the final display. For 21 of the 42 infants tested, the primary observer guessed whether the infants had seen two identical objects or two different objects when the screen was lowered. The primary observer guessed correctly for only 9 of the 21 infants, a performance not significantly different from chance (cumulative binomial, $p > 0.05$).

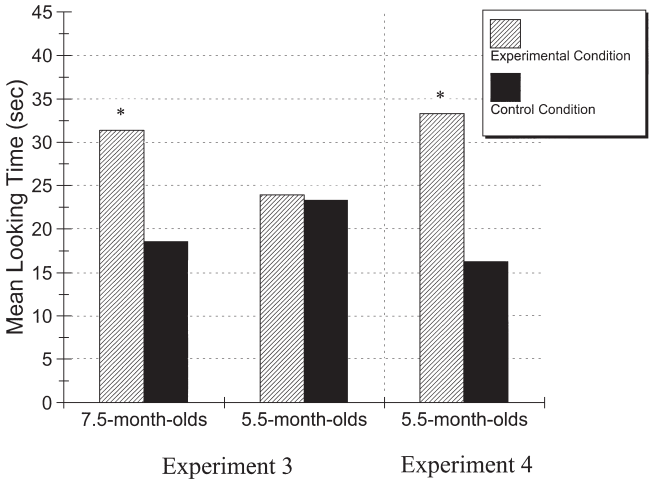

Figure 5 *Mean looking times of the infants in Experiments 3 and 4 during the final phase of the test event.*

Together, these results suggest that the 7.5-month-olds represented the egg-column event as involving two specific objects, an egg and a column, and were surprised to see two columns when the screen was lowered. In contrast, the 5.5-month-olds responded as if they had failed to detect the discrepancy between the featural properties of the objects seen in the initial and final phase of the experimental event.

Additional results

There is, however, an alternative explanation for the positive results obtained with the older infants that is equally plausible and does not involve mapping of specific features. It is possible that the infants represented the egg-column event as involving two objects that differed in their featural composition, and hence were surprised to see two identical objects when the screen was lowered. This explanation differs from the first explanation in that it suggests that the infants represented the initial event as 'two different objects' rather than as 'an egg and a column'. To investigate this possibility, 7 infants (4 males, 3 females, M = 8 months, 2 days; range = 7 months, 13 days to 8 months, 9 days) were tested in a modified experimental condition. Infants again saw a two phase test event. In the initial phase, a triangle moved behind the left side of the screen and a column emerged at the right side. Before the screen was lowered the triangle was surreptitiously replaced with the egg, so that the final display contained an egg and a column. Prior to the test event infants saw three pretest displays: a triangle to the left of the screen, a column to the right and an egg to the left. Infants were presented with three pretest-display trials so that they had equal exposure to each of the three objects, in the order that they were seen in the test event, prior to the test trials.[7]

If the 7.5-month-old experimental infants looked longer at the final display because they represented the different-features (i.e. egg-column) event as involving two specific objects (i.e. an egg and a column) and were surprised when the final display failed to contain those two objects, then the infants in the modified experimental condition, who also saw a different-features (i.e. triangle-column) event should be surprised when the final display contained the incorrect objects (i.e. an egg and a column). In contrast, if the experimental infants looked longer at the final display simply because they expected to see two featurally different objects when the screen was lowered, then the infants in the modified experimental condition should not be surprised by the egg-and-column display.

The mean looking times of the infants in the modified experimental condition were compared to those of the infants in the experimental and control conditions by means of a one-way ANOVA with condition (modified experimental, experimental, control) as a between-subjects factor. The analysis yielded a significant main effect of condition, $F(2, 18) = 4.08$, $p < 0.05$. Planned contrasts revealed that the infants in the modified experimental condition (M = 36.2 s, SD = 14.5) looked reliably longer than those in the control condition, $F(1, 18) = 7.67$), $p < 0.01$, but did not differ reliably in their looking times from those in the original experimental condition, $F(1, 18) = 0.57$, $p > 0.05$. These results suggest that when the final display contained two different objects, and the featural composition of those objects did *not* match those seen in the initial phase, the infants found the final display unexpected or surprising.

Of course, one might again be concerned that the pattern of results obtained here could be explained by lower level perceptual processes. For example, perhaps the infants found it more intriguing to view pretest and test events in which three different objects were presented (modified experimental condition) than pretest and test events in which only two objects were presented (experimental and control conditions), leading to increased looking during the final display. This explanation might

[7] In designing the modified experimental condition, we could have presented infants with the egg-column event and changed the objects seen in the final phase of the event (i.e. a triangle and a column rather than an egg and a column). However, such a design could potentially make interpretation of differences in looking times to the final displays problematic. For example, if the infants in the modified experimental condition looked longer than the infants in the experimental condition, one could argue that the infants simply preferred to see a display containing a triangle and a column than an egg and a column. To avoid such difficulties we opted, instead, to alter the objects seen in the initial phase of the test event.

account for why the infants in the modified experimental condition (who saw three different objects in the pretest and test trials) looked reliably longer than the infants in the control condition (who saw two different objects in pretest and test trials), but it cannot account for why the infants in the experimental condition (who saw two different objects in pretest and test trials) also responded with increased looking. Hence, we would suggest that the most parsimonious explanation is the one already offered: the infants in the experimental and modified experimental conditions looked longer at the final display because the objects seen in the initial phase of the event did not map onto the objects seen in the final phase of the event.

Discussion

The 7.5-month-olds in the experimental condition looked reliably longer at the final display than those in the control condition, as if the infants had: (a) represented the egg-column event as involving two featurally distinct objects, an egg and a column; (b) compared their representation of the initial event to the final display; and (c) found the presence of two columns, but not an egg and a column, inconsistent with this representation. The results of a follow-up experiment provided additional evidence that 7.5-month-olds represent different-features events as involving two distinct objects, specified by their featural composition.

In contrast, the 5.5-month-olds in the two conditions looked about equally during the final phase of the test event, as if they were unable to detect a discrepancy between the initial egg-column event and the presence of two columns in the final display. Recall, however, that the 5.5-month-old infants in Experiment 2 detected a discrepancy between the egg-column event and the presence of only *one* column in the final display. Together, these results suggest that when faced with the task of mapping a different-features occlusion event onto a no-occlusion display, 5.5-month-olds expect to see two objects when the screen is lowered but hold no expectation for the featural properties of those objects.

Although one might conclude from these results that 7.5-month-olds, but not 5.5-month-olds, can successfully retrieve and compare object features across event representations, such a conclusion might be premature. There is evidence that infants find it easier to interpret and map occlusion events when spatiotemporal information signals the presence of distinct objects (Kaldy & Leslie, 2001; Spelke *et al.*, 1995; Wilcox & Schweinle, 2001; Xu & Carey, 1996). Perhaps if infants were provided with unambiguous spatiotemporal information as to the number of objects present they might be more likely to succeed at mapping the featural properties of the objects involved. The next experiment tested this hypothesis.

Experiment 4

Infants 5.5 months of age were presented with the egg-column event of Experiment 3 with one exception: the wide screen was replaced by two narrow screens (Figure 6). In the initial phase of the event, the egg moved behind the left screen and then the column emerged from behind the right screen (no object appeared between the two screens). When the screens were lowered, infants saw either two columns (experimental condition) or an egg and a column (control condition) on the platform. Now the infants no longer needed to rely on featural information to individuate the objects; the discontinuity in path of motion clearly specified the presence of two distinct individuals. If providing spatiotemporal cues as to the number of objects present facilitates mapping performance, then the 5.5-month-olds in Experiment 4 should detect the discrepancy between the initial egg-column event and the final two-column display.

Method

Participants

Participants were 14 5.5-month-olds, 7 male and 7 female (M = 5 months, 18 days; range = 5 months, 6 days to 6 months, 2 days). Two additional infants were eliminated from the experiment because of procedural problems (one infant grabbed the screen and one was distracted by a sibling). Seven infants were randomly assigned to the experimental (M = 5 months, 19 days) and the control (M = 5 months, 18 days) condition.

Apparatus, events and procedure

The apparatus and stimuli were identical to those used in Experiment 3 with one exception: the wide screen was replaced with two narrow screens. The screens were 11.5 cm wide and 36 cm tall, made of cardboard, covered with green contact paper, and attached to the wooden dowel with metal clips. The right edge of the left screen and the left edge of the right screen were placed 4 cm from the center of the platform.

The pretest displays, test events and procedure were identical to those used with the 5.5-month-olds in Experiment 3, except that the two narrow screens replaced the wide screen. Inter-observer agreement during the final

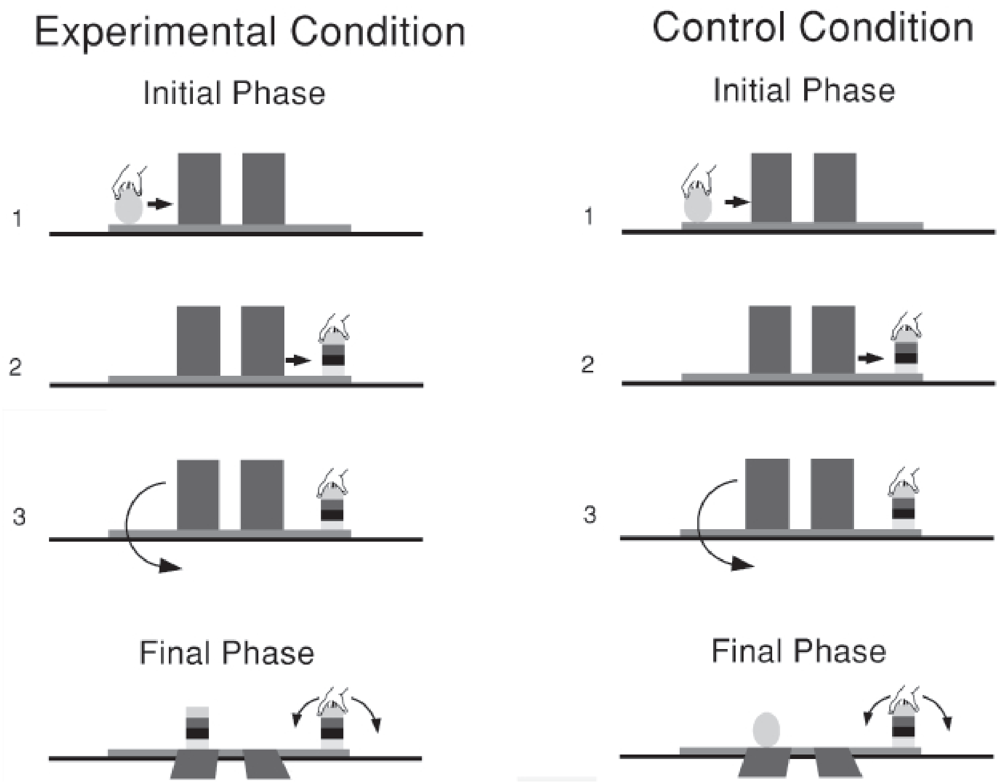

Figure 6 *Schematic drawing of the test events in the experimental and control conditions of Experiment 4.*

phase of the test trial was measured for 11 infants and averaged 90%.

Results

Pretest-display trials

The infants' mean looking times for the first trial pair (*M* of trials 1 and 3) and the second trial pair (*M* of trials 2 and 4) were analyzed by means of a mixed-model ANOVA with trial pair (first or second) as a within-subjects factor and condition (experimental or control) as a between-subjects factor. The main effect of trial pair was significant, $F(1,12) = 7.04$, $p < 0.025$, indicating that the infants looked reliably longer during the first trial pair ($M = 43.4$, $SD = 13.6$) than the second trial pair ($M = 34.2$, $SD = 19.5$). The main effect of condition and the trial pair × condition interaction were not significant, *F*s < 1, indicating that the infants in the experimental (first pair, $M = 44.9$ s, $SD = 15.3$, second pair, $M = 36.0$ s, $SD = 23.1$) and the control (first pair, $M = 41.8$ s, $SD = 12.7$, second pair, $M = 32.3$ s, $SD = 16.7$) condition did not differ reliably in their mean looking times across the two pairs of pretest trials.

Test trials

The infants' looking times during the final phase of the two test trials were averaged (Figure 5) and analyzed by means of a one-way ANOVA. The main effect of Condition was significant, $F(1, 12) = 8.04$, $p < 0.025$, indicating that the infants in the experimental condition ($M = 33.3$ s, $SD = 14.8$) looked reliably longer than those in the control condition ($M = 16.3$ s, $SD = 5.8$).

Additional results

To examine why the 5.5-month-olds found the two-column display unexpected, 7 5.5-month-olds (2 males, 5 females, $M = 5$ months, 21 days; range = 5 months, 10 days to 6 months, 5 days) were tested in the modified experimental condition of Experiment 3 with the following exceptions: (a) the wide screen was replaced with the two narrow screens; (b) the infants saw six rather than three pretest-display trials (i.e. the triangle, column, egg sequence was seen two times); and (c) the pretest-display trials ended when the infant looked away for 2 consecutive seconds after having looked for at least 5 cumulative seconds or looked for 60 cumulative seconds (the same criteria used for the 5.5-month-olds in Experiments 2 and 3).

The looking times of the infants in the modified experimental condition were compared to those of the infants in the experimental and control conditions by means of a one-way ANOVA with Condition (modified experimental, experimental, control) as a between-subjects factor. The analysis yielded a significant main effect of condition, $F(2, 18) = 6.38$, $p < 0.01$. Planned contrasts revealed that the infants in the experimental condition looked reliably longer than those in the modified experimental condition ($M = 20.7$ s, SD = 6.9), $F(1, 18) = 5.46$, $p < 0.05$, and that the looking times of the infants in the modified experimental and the control condition did not differ reliably from each other, $F(1, 18) = 0.68$, $p > 0.05$. These results suggest that the 5.5-month-olds viewed the final egg-column display as consistent with either the egg-column or the triangle-column event, as if they had represented the event as simply involving 'two featurally different objects'.

Discussion

When the egg-column event was seen with two screens separated by a gap, so that the objects could be individuated using spatiotemporal information, the 5.5-month-olds looked reliably longer at a final display containing two columns than an egg and a column, as if the infants had successfully judged that the egg-and-column, but not the two-column, display was consistent with the initial egg-column event. Additional results suggested, however, that the infants responded in this fashion because they had encoded the event as 'two featurally distinct objects' rather than as 'an egg and a column'.

The positive results obtained in Experiment 4, when two spatially separate screens were used, provide an interesting contrast to the negative results obtained with the 5.5-month-olds in Experiment 3, when a single wide screen was used. When the egg and the column could *only* be individuated using featural information, 5.5-month-olds responded as if they expected to see two objects when the screen was lowered but were unconcerned with what those objects should look like. In contrast, when the egg and the column could be individuated using spatiotemporal information, the infants evidenced at least some measure of success: now the infants responded as if they expected to see not only two objects, but two objects that differed in their featural composition. Reasons for why the infants were more successful when spatiotemporal information specified the presence of two objects are offered in the General Discussion.

General discussion

The present research examined the development of young infants' ability to map different-features occlusion events using a simplified event-mapping task. Four experiments were conducted with 7.5-, 5.5- and 4.5-month-old infants. Experiments 1 and 2 assessed infants' ability to judge whether the final display contained the correct number of objects, whereas Experiments 3 and 4 examined infants' ability to judge whether the objects seen in the initial and final phases of the test event were consistent in their featural composition. At 7.5 and 5.5 months, but not at 4.5 months, infants successfully mapped an egg-column event onto a subsequent one-column display. However, the 7.5- and 5.5-month-olds differed in the way that they represented the egg-column event. Whereas the 7.5-month-olds represented the event as involving two specific objects, an egg and a column, the 5.5-month-olds represented the event as simply involving 'two objects'. When the objects could be individuated on the basis of spatiotemporal information, however, 5.5-month-olds succeeded at tagging the objects as being featurally distinct, although they still failed to attach more specific information about what those differences were.

These results raise two important questions: (1) How can infants draw on features to set up numerically distinct representations of objects, yet fail to include those features into their object representations? and (2) Why does the introduction of spatiotemporal cues facilitate the retrieval of more detailed information about the objects involved? We believe that these questions are related and can be answered together.

Identifying the simple structure of physical events

One possibility is that mapping performance is constrained by the hierarchical way that information is processed and used. According to this account, when building representations of physical events infants' first and primary task is to identify the simple structure of the event (Wilcox *et al.*, in press). The simple structure includes what objects are present, where they are and the nature of their interaction (i.e. the spatial and mechanical properties of the objects). Only after the simple structure has been identified are infants able to move on to the task of incorporating more detailed information about the event, such as the featural properties of the objects. (Of course, infants detect featural differences, or they would not be able to individuate the objects. However, they do not encode those features in a way that ensures retrieval in a subsequent event.) If any part of the event is ambiguous, so that the simple structure cannot be fully identified, infants will have difficulty integrating featural information into their event representations. Occlusion events naturally contain some ambiguity, because they require reasoning about occluded trajectories. Different-features occlusion events, in which different objects are seen to each side of the screen, are especially difficult because one object stops and the other begins its path of motion when behind the screen. Making the simple structure more explicit, by providing information as to the number of objects present and their spatiotemporal coordinates (i.e. in the present experiments this was accomplished by having the objects move behind spatially separate screens), allows infants to encode more detailed information about the event. Presumably, as infants become more skilled at extracting the simple structure, they have the resources available to integrate more specific information about how the objects differ. This account is supported, at least in part, by recent evidence that infants are more likely to demonstrate success on event-mapping tasks when (a) the simple structure of the event is fully specified prior to the test trials (e.g. Xu & Carey, 1996) or (b) when infants are shown an 'outline' of the event, prior to the test trials, to help them to identify the simple structure (Wilcox, 1999a).

Binding features to objects

Another possibility is suggested by recent research in object-based representation. The issue of how and when features get linked to objects has been referred to as the 'binding problem' (e.g. Treisman, 1995). For example, according to object file theory (Kahneman & Treisman, 1984; Kahneman, Treisman & Gibbs, 1992; Treisman, 1988, 1995), we are equipped with temporary structures where information about currently visible objects is collected, called object files. An object file (i.e. the percept of a new object) is created when object properties (e.g. location, color, shape) are believed to have changed. To use a familiar example, seeing the egg to one side of the screen would initiate the opening of one object file, whereas seeing the column to the other side of the screen would result in the opening of another. Object files contain information about both the spatiotemporal and the featural properties of objects, although they are addressed primarily by spatiotemporal coordinates. Soon after objects disappear from view, or can no longer be directly perceived, object files are stored as memory tokens. However, because information about the spatiotemporal and featural properties of objects is processed and stored separately, a view supported by research in the neurosciences (Desimone & Ungerleider, 1989; Ungerleider & Mishkin, 1982), a unified representation requires that they be joined together in some way. If this information is not joined together, then one may retrieve information about where an object was located, or what features were present, without being able to specifying which features were located where. When in view, the 'glue' that binds features to objects is focused attention. When out of view, features and locations may continue to be perceived as unitary objects for a short time; however, with memory decay the features may 'float free' (Treisman, 1977). Hence, even though featural information may be used to initiate the opening of a new object file, it is not necessarily the case that it is permanently integrated into object representations.

Furthermore, some researchers have recently suggested that the mechanism responsible for binding together object properties is not well developed in the young infant (Leslie *et al.*, 1998). One interpretation of the differential performance of the 7.5- and 5.5-month-olds in Experiment 3, then, is that the younger infants had difficulty binding the features to the objects. How might this work? According to Treisman (1995), the binding problem can take on many different forms. For example, in location binding, objects are bound to their spatiotemporal coordinates and, by extension, moving objects are bound to their trajectories. In contrast, in property binding, features are bound to objects. It is possible that, within the context of physical events, infants must first bind objects to their trajectories before they can bind features to the objects. In the egg-column event, this would require identifying the trajectory that each object followed, including where each object stopped, started and reversed direction when behind the screen. As we have already suggested, the task of representing occluded trajectories may be particularly difficult for young infants. When the objects' trajectories were made explicit, by having the objects move behind spatially separate screens, objects could easily be bound to their spatiotemporal coordinates, making feature binding possible. However, because featural information decays, or becomes 'unglued', more quickly in younger infants, the 5.5-month-olds evidenced a less clear 'picture' of the what those featural differences were.

Concluding remarks

We have presented the 'simple structure' and the 'feature binding' hypotheses as if they were two separate and distinct possibilities. However, it is quite likely that they complement rather than compete with each other. For example, the former may explain how infants go about building representations of physical events in general (i.e. infants must identify the simple structure before they can attend to more detailed information), whereas the latter suggests a mechanism for how infants go about integrating object properties to form percepts of individuals that persist through occlusion. It may be a combination of these two approaches that will ultimately lead to the development of a more unified model of object representation in infancy.

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References

Aguiar, A., & Baillargeon, R. (in press). Developments in young infants' reasoning about occlusion events. *Cognitive Psychology*.

Baillargeon, R. (1995). A model of physical reasoning. In C. Rovee-Collier & L.P. Lipsitt (Eds.), *Advancess in infancy research*, Vol. 9 (pp. 305–371). Norwood, NJ: Ablex.

Baillargeon, R. (1998). Infants' understanding of the physical world. In M. Sabourin, F.I.M. Craik & M. Robert (Eds.), *Advances in psychological science: Vol. 1 Cognitive and biological* aspects (pp. 503–529). London: Psychology Press.

Baillargeon, R., Graber, M., DeVos, J., & Black, J. (1990). Why do young infants fail to search for hidden objects? *Cognition*, **36**, 225–284.

Chapa, C., & Wilcox, T. (2000). Event-mapping tasks: testing assumptions about event categorization. Paper presented at the International Conference on Infant Studies, Brighton, UK, July.

Cornell, E.H. (1979). Infants' recognition memory, forgetting, and savings. *Journal of Experimental Child Psychology*, **28**, 359–374.

Desimone, R., & Ungerleider, L.G. (1989). Neural mechanisms of visual processing in monkeys. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (Vol. 2, pp. 267–299). New York: Elsevier.

Fagan, J. (1974). Infant recognition memory: the effects of length of familiarization and type of discrimination task. *Child Development*, **45**, 351–356.

Fagan, J. (1977). Infant recognition memory: studies in forgetting. *Child Development*, **48**, 68–78.

Hespos, S. (2000). Tracking individual objects across occlusion and containment events in 6.5-month-old infants. Paper presented at the International Conference on Infant Studies, Brighton, UK, July.

Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D.A. Davies (Eds.), *Varieties of attention*. New York: Academic Press.

Kahneman, D., Treisman, A., & Gibbs, B. (1992). The reviewing of object files: object-specific integration of information. *Cognitive Psychology*, **24**, 175–219.

Kaldy, Z., & Leslie, A.M. (2001). Identification of objects in 9-month-old infants: the role of location. Manuscript submitted for publication.

Leslie, A., Xu, F., Tremoulet, P., & Scholl, B. (1998). Indexing and the object concept: developing 'what' and 'where' systems. *Trends in Cognitive Sciences*, **2**, 10–18.

Rose, S.A., Gottfried, A.W., Melloy-Carminar, P., & Bridger, W.H. (1982). Familiarity and novelty preferences in infant recognition memory: implications for information processing. *Developmental Psychology*, **18**, 704–713.

Scholl, B.J., & Leslie, A.M. (1999). Explaining the infants' object concept: beyond the perception/cognition dichotomy. In E. Lepore and S. Pylyshyn (Eds.), *What is cognitive science*? Oxford: Blackwell.

Spelke, E.S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*, **99**, 605–632.

Spelke, E.S., Kestenbaum, R., Simons, D.J., & Wein, D. (1995). Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology*, **13**, 113–143.

Treisman, A. (1977). Focused attention in the perception and retrieval of multidimensional stimuli. *Perception and Psychophysics*, **22**, 1–11.

Treisman, A. (1988). Features and objects: the 14th Bartlett memorial lecture. *The Quarterly Journal of Experimental Psychology*, **40**, 201–237.

Treisman, A. (1995). The binding problem. *Current Opinion in Neurobiology*, **6**, 171–178.

Tremoulet, P.D., Leslie, A.M., & Hall, G.D. (2001). Infant individuation and identification of objects. *Cognitive Development*, **15**, 499–522.

Ungerleider, L., & Mishkin, M. (1982). Two cortical visual systems. In D.J. Ingle, M.A. Goodale & R.J.W. Mansfield (Eds.), *Analysis of visual behavior*. Cambridge, MA: MIT Press.

Wilcox, T. (1999a). Infants' event representations: extracting the simple structure. Paper presented at the Biennial Meeting of the Society for Research in Child Development, Albuquerque, NM, April.

Wilcox, T. (1999b). Object individuation: infants' use of shape, size, pattern, and color. *Cognition*, **72**, 125–166.

Wilcox, T., & Baillargeon, R. (1998a). Object individuation in infancy: the use of featural information in reasoning about occlusion events. *Cognitive Psychology*, **37**, 97–155.

Wilcox, T., & Baillargeon, R. (1998b). Object individuation in young infants: further evidence with an event monitoring task. *Developmental Science*, **1**, 127–142.

Wilcox, T., & Chapa, C. (2001). Priming infants to attend to color and pattern information in an individuation task. Submitted for publication.

Wilcox, T., & Chapa, C. (in press). Infants' reasoning about opaque and transparent occluders in an individuation task. *Cognition.*

Wilcox, T., Nadel, L., & Rosser, R. (1996). Location memory in healthy preterm and full-term infants. *Infant Behavior and Development*, **19**, 309–323.

Wilcox, T., & Schweinle, A. (2001). Infants' use of object speed to individuate objects in occlusion events. Manuscript submitted for publication.

Wilcox, T., Schweinle, A., & Chapa, C. (in press). Object individuation in infancy. In F. Fagan & H. Hayne (Eds.), *Progress in infancy research* (Vol. 3). Mahway, NJ: Lawrence Erlbaum Associates.

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

Xu, F., & Carey, S. (1996). Infants' metaphysics: the case of numerical identity. *Cognitive Psychology*, **30**, 111–153.

Xu, F., & Carey, S. (2000). The emergence of kind concepts: a rejoinder to Needham & Baillargeon (2000). *Cognition*, **74**, 285–301.

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