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Sex Differences During Visual Scanning of Occlusion Events in Infants

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A growing number of sex differences in infancy have been reported. One task on which they have been observed reliably is the event-mapping task. In event mapping, infants view an occlusion event involving 1 or 2 objects, the occluder is removed, and then infants see 1 object. Typically, boys are more likely than girls to detect an inconsistency between a 2-object occlusion event and a 1-object display. The current research investigated underlying reasons for this sex difference. Three eye-tracking experiments were conducted with infants at 9 and 4 months (mean age). Infants saw a ball-box or ball-ball occlusion event followed by a 1-ball display; visual scanning of the occlusion event and the 1-ball display was recorded. Older boys were more likely than older girls to visually track the objects through occlusion and more likely to detect an inconsistency between the ball-box event and the 1-ball display. In addition, tracking objects through occlusion was related to infants' scanning of the 1-ball display. Both younger boys and girls failed to track the objects through occlusion and to detect an inconsistency between the ball-box event and the 1-ball display. These results suggest that infants' capacity to track objects through occlusion facilitates extraction of the structure of the initial event (i.e., the number of distinct objects involved) that infants can map onto the final display and that sex differences in the capacity emerge between 4 and 9 months. Possible explanations for how the structure of an occlusion event is extracted and mapped are considered.

Keywords: infants, object processing, sex differences, occlusion, eye tracking

One of the more intriguing characteristics of human cognition is that of sex differences. The identification of robust and pervasive sex differences in children and adults (Levine, Huttenlocher, Taylor, & Langrock, 1999; Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995) has generated a great deal of debate about where these differences originate and what biological and environmental factors contribute to their existence. In an attempt to better understand the origins of sex differences, some investigators have looked to infancy research, where cognitive functioning can be examined prior to extensive social and educational experiences. Investigations with infants have revealed a wide range of sex differences (Alexander, 2003; Antell & Keating, 1983; Benenson, Duggan, & Markovits, 2004; Creighton, 1984; Kavšek, 2004; Lutchmaya & Baron-Cohen, 2002; Moore & Cocas, 2006; Serbin, Poulin-Dubois, Colburne, Sen, & Eichstedt, 2001; Servin, Bohlin, & Berlin, 1999). In some cases, sex differences have been observed in infants' preference for one type of visual stimulus over another. For example, there is evidence in 3- to 12-month-olds that boys compared with girls prefer a boy-typed toy, such as a truck, whereas girls compared with boys prefer a girl-typed toy, such as a doll (Alexander, Wilcox, & Woods, 2009; Jadva, Hines, & Golombok, 2010). In other cases, sex differences have been observed in infants' ability to interpret visual displays. For example, investigators have reported that 3- to 5-month-old boys compared with girls are more likely to prefer a mirror than a rotated image of previously viewed objects (Moore & Johnson, 2008; Quinn & Liben, 2008). The goal of the present research was to take a complex cognitive task on which sex differences have been observed and identify the underlying basis for those differences.

One task that has reliably produced sex differences in performance during infancy is the event-mapping task (Schweinle & Wilcox, 2004; Wilcox, 2003, 2007). In an event-mapping task, infants see a test event composed of two parts, an occlusion sequence followed by a no-occlusion display. An example of an event-mapping task is displayed in Figure 1A. During the initial (occlusion) phase of the task, infants see either two distinct objects (ball–box event) or the same object (ball–ball event) move to opposite sides of the screen. During the final (no-occlusion) phase of the task, the screen is lowered to reveal one-object on the platform; infants' looking to the one-object display is recorded. By 11.5 months infants show prolonged looking to the final one-ball display after viewing a ball–box but not a ball–ball occlusion sequence, suggesting that infants perceived the ball–box (but not the ball–ball) event as involving two distinct objects and found the final one-object display unexpected (Wilcox & Baillargeon, 1998a). There is evidence, however, that boys and girls exhibit

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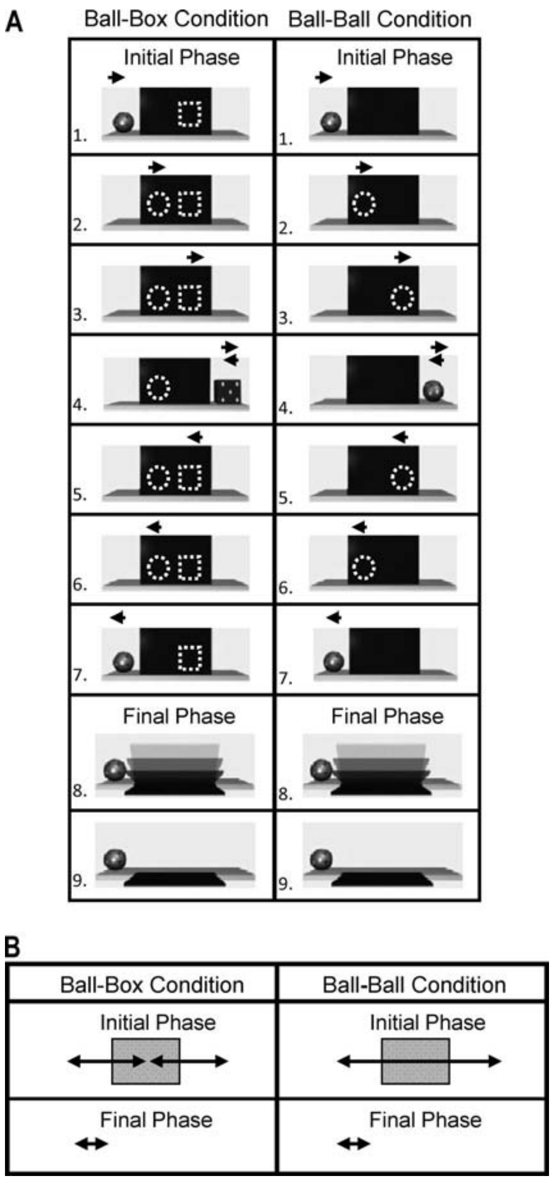

Figure 1. A: The ball–box and ball–ball test events used in the present research. The dotted shapes represent the location of the object(s) when behind the screen and not visible to the infant. B: The simple structure of the ball–box and ball–ball events.

different development trajectories in their performance on this task. In one study, boys first detected an inconsistency between a ball–box event and a final one-ball display at 10.5 months, while girls first detected this inconsistency at 11.5 months (Wilcox, 2007). Similar sex differences, favoring boys, have been reported in other event-mapping tasks. For example, in another study boys detected an inconsistency between a speed–discontinuity event (i.e., one object disappears behind one edge of a screen, and a second object appears immediately at the other edge) and a one-object display by 7.5 months while girls detected this inconsistency at 9.5 months (Schweinle & Wilcox, 2004).

In order to explain group differences in infants' performance on event-mapping tasks, one must first understand the cognitive processes in which infants engage during such tasks. There is evidence that when infants see an occlusion sequence followed by a no-occlusion display, they perceive these as two categorically distinct events (Wilcox & Baillargeon, 1998a; Wilcox & Chapa, 2002; see also Wang & Baillargeon, 2006, 2008). Successful performance depends on infants' ability to compare their representation of the first (occlusion) event with that of the second (no-occlusion) event and determine whether the two are compatible. For example, infants must compare the number of objects in the first event with those in the second event and detect if inconsistencies exist between these. This process breaks down when infants are unable to form a clear representation of the occlusion event (Baillargeon et al., in press; Wilcox, 2003) that they can map onto the no-occlusion event. This is particularly difficult when the occlusion event is lengthy and complex (e.g., the objects reverse direction of motion and undergo multiple occlusions). Limited information-processing capacities—for example, limited visual short-term or working memory (Oakes, Hurley, Ross-Sheey, & Luck, in press; Ross-Sheehy, Oakes, & Luck, 2003)—constrain infants' ability to represent the entire event from beginning to end. Success rests on infants' ability to identify the simple structure of the initial event—the number of distinct objects and their spatiotemporal coordinates—and to map the simple structure onto the final display. To illustrate, it is easier to retrieve and map the simple structure of the ball–box and ball–ball events displayed in Figure 1B than the entire event sequence displayed in Figure 1A.

There are several lines of evidence that support hypothesis. First, if infants are given help in identifying the simple structure of a complex event, by tagging the individuals with labels (Xu, 2002; Xu, Cote, & Baker, 2005) or by showing infants the basic components of the occlusion sequence prior to the test trials (Wilcox, 2003), they are more likely to succeed on event-mapping tasks. Second, if the objects follow a single trajectory across the platform and never change direction, so that the occlusion sequence is simple and easy to remember, then infants demonstrate improved performance on event-mapping tasks (Wilcox & Baillargeon, 1998a; Wilcox & Schweinle, 2002). In addition, the concept of forming structured representations of events, and comparing these representations, is consistent with a long-standing and prominent model of adult cognition. According to structure mapping theory (Gentner, 1983; Gentner & Markman, 1994; Markman & Gentner, 1997), many cognitive tasks require one to compare the structure of one event with that of another. That is, one does not necessarily retrieve entire events to compare but instead accesses the basic structure of those events. The comparison process involves aligning two structured representations and then determining whether the elements of one representation (i.e., the objects, the attributes of the objects, and/or the relations between the objects) are consistent with those of a second representation. Structural comparison has been studied in children with a wide range of cognitive tasks, and generally speaking, the more explicit or better understood the structure of a representation, the more likely children are to map that representation onto a new problem context (Brown, Kane, & Echols, 1986; Gentner, Loewenstein, & Hung, 2007; Gentner & Namy, 1999; Gentner & Toupin, 1986; Loewenstein & Gentner, 2001). Similarly, successful performance on event-mapping tasks such as the one shown in Figure 1A requires infants to identify the basic structure of the first event (one object or two objects) and to compare that structure with that of the second event (one object).

Thus, one explanation for sex differences observed in event-mapping tasks is that boys have a greater capacity to extract the simple structure of occlusion events, which they can then map onto a subsequent display (Schweinle & Wilcox, 2004; Wilcox, 2003, 2007).[1] What would lead to such advantage? One possibility is that boys are better able than girls to identify the spatiotemporal coordinates of moving occluded objects. For example, in the ball–box event one object moves on a trajectory behind the left side of the screen and another object moves on a trajectory behind the right side of the screen. Extracting the simple structure of occlusion events depends critically on the ability to track paths of motion, even when these paths move from view and their beginning and/or end points must be extrapolated (the ball and box stop and start paths of motion when occluded). It is only when spatiotemporal coordinates have been identified, and the simple structure of the event extracted, that infants can correctly identify whether the number of objects seen in the initial occlusion event is consistent with the number of objects seen in the final display. One way to begin to test this hypothesis is to investigate the processes in which infants engage during the occlusion sequence. The present research used eye-tracking technology to this end.

We chose eye-tracking methods to investigate the underlying basis for sex differences in event-mapping performance for two reasons. First, eye-tracing methods provide a more reliable measure of active visual processing than do global looking time methods, and they allow researchers to assess distribution of visual attention to components of the display rather than to the display as a whole (Aslin, 2007). The result is a more sensitive measure of individual and group differences in performance. Second, patterns of visual scanning, including direction of gaze, can provide insight into the cognitive processes in which infants engage when attending to a visual display (Aslin, 2004; Hayoe, 2004). With this in mind, we assessed visual scanning during the two phases of an event-mapping task: the initial occlusion sequence and the final no-occlusion display. On the basis of previous results obtained using a violation-of-expectation task (Wilcox, 2003, 2007), we expected male and female infants to display different patterns of scanning to the final no-occlusion display. In addition, we explored whether (a) sex differences would emerge in infants' scanning of the initial occlusion sequence and (b) whether these sex differences were related to sex differences in scanning of the final display. The goal was to determine whether boys and girls engaged in different processes during the occlusion sequences and the extent to which this predicted their ability to interpret the final display.

Experiment 1

Infants ages 6–10 months with a mean age of 9 months were presented with a box–ball or ball–ball occlusion sequence followed by a one-ball display (see Figure 1A). Previous event-mapping experiments, which have relied solely on duration of looking to the final display as the dependent measure, reported sex differences at 10.5 months (Wilcox, 2007). That is, male but not female infants who saw the ball–box occlusion sequence demonstrated prolonged looking to the final one-ball display. We expected that eye-tracking technology would provide a more sensitive assessment of infants' event-mapping capacities and, hence, that sex differences might be observed prior to 10.5 months.

Method

Participants. Thirty-six healthy, term infants participated (18 male, 18 female; $M_{\text{age}} = 9$ months 3 days; range = 6 months 18 days to 10 months 2 days). Parents reported their infant's race/ethnicity: Caucasian ($n = 29$), Hispanic ($n = 3$), Native American ($n = 2$), and other ($n = 2$). Five additional infants were tested but not included in the analyses because of fussiness ($n = 4$) or failure to look at the display once testing began ($n = 1$). An equal number of male and female infants were pseudorandomly assigned to one of two groups: ball–box (male $M_{\text{age}} = 9$ months 8 days, range = 8 months 1 day to 10 months 2 days; and female $M_{\text{age}} = 9$ months 4 days, range = 8 months 12 days to 9 months 23 days) and ball–ball (male $M_{\text{age}} = 8$ months 25 days, range = 6 months 18 days to 9 months 29 days; and female $M_{\text{age}} = 9$ months 6 days, range = 7 months 26 days to 10 months 2 days). In this and the following experiments, parents and infants were recruited from birth announcements in the local newspaper and commercially produced lists. The study protocol was approved by the relevant institutional review board. The experimental procedure was explained to the parents, and informed consent was obtained prior to testing. The parents were offered $5 or a lab T-shirt for participation.

Experimental setup. Test events (see Figure 1A) were animated and presented on a 20-in. video monitor in a darkened room (no room lighting was used). Infants sat in a car seat approximately 56 cm from the computer screen. On the video monitor the blue occluding screen was 16.5 cm wide and 10 cm tall and centered on the path on which the object(s) moved. The green ball was 4.5 cm in diameter and had multicolored dots; the red box was 5.5 cm square and had white dots. The length of the platform on which the objects moved was 33.5 cm. An infrared eye tracker with remote optics (Model R6, Applied Science Laboratories) measured eye movements during the test trials. The camera was located directly below the computer monitor and was not visible to the infants. A magnetic head tracker (Flock of Birds, Ascension Technology Corporation) was worn by infants to limit any disruption in eye tracking as a function of head movement. To obtain reliable and valid eye movement data, three gaze positions within the viewing area were first collected using swirling light stimuli to direct the infants' attention to each of the three points successively. After successful calibra-

[1] One might question whether sex differences reported in event-mapping experiments reflect differences in the capacity to individuate objects, more generally, rather than differences in event-mapping abilities. There is converging evidence from violation-of-expectation and search tasks that infants from 4.5 to 11.5 months interpret a different-features (e.g., ball–box) occlusion sequence as involving two distinct objects and a same-features (e.g., ball–ball) occlusion sequence as involving a single object (McCurry, Wilcox, & Woods, 2009; Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b; Xu & Baker, 2005), and sex differences have not been observed in these tasks. It is only when an event-mapping task is used that sex differences emerge.

tion, each infant was presented with three test trials with the event (see later) appropriate for their experimental condition.

Events.

Ball–box condition. Each test trial consisted of an initial phase and a final phase. The initial phase began with the ball sitting at the left edge of the platform. The ball moved to the right until it was fully hidden by the screen (2 s), a box emerged from behind the screen and moved to the right edge of the platform (2 s), the box paused (1 s), and then the 5-s sequence was seen in reverse. When in motion, the objects moved at a rate of 7.13 cm/s and the occlusion interval was 1.8 s. Once the ball returned to its starting position, the screen was lowered (2 s); this marked the beginning of the final phase of the test trial. Infants were allowed 5 s to view the final display, which consisted of the ball to the left of the lowered screen and an otherwise empty platform.

Ball–ball event. The ball–ball event was identical to the ball–box event except that the ball, rather than a box, emerged to the right of the screen.

Infants were presented with three test trials of the event appropriate for their experimental condition. Ten infants contributed data for only one or two trials because of a failure to look or because the eye tracker was unable to track their gaze (missing 17 of a possible 108 trials).

Coding: Initial phase. Two time periods of interest were identified. These were *full occlusion* (i.e., the time during which the objects were entirely occluded) and *no occlusion* (i.e., the time during which an object was visible to the left or the right of the screen). Duration of visual scanning to areas of interest (AOIs) during these time periods was the dependent variable. Visual fixations, system-defined as a period of at least 100 ms during which point of regard did not change by more than 1 degree of visual angle, were also coded. However, because the fixation results were the same as those of the duration of looking results, fixation data are not reported.

Full occlusion. First, the visual display was divided into three AOIs: the screen, the end of the platform at which the object was last seen, and the end of the platform at which the object would next appear (see Figure 2A). The duration of time (in seconds) that infants spent scanning these three AOIs during the occlusion interval were calculated. The following percentage scores were computed: screen (scanning the screen/scanning all three AOIs), look back (scanning the side of the platform where the object was last seen/scanning all three AOIs), and anticipation (scanning the side of the platform where the object would next appear/scanning all three AOIs).

Second, of the time that infants spent scanning the screen, the duration of time that infants spent scanning the side of the screen that currently hid the moving object was calculated. For each trial there were two occlusion intervals: Occlusion 1, as the event moved left to right behind the screen, and Occlusion 2, as the event moved right to left behind the screen (see Figure 2B). Because the location of the object behind the screen moved as the occlusion interval progressed, the side of the screen that hid the moving object was time-dependent. To create AOIs, the screen was divided into two halves and the occlusion intervals were divided into two equal time periods: A (the first half of the occlusion period) and B (the second half of the occlusion period). Hence, four time and location AOIs were created that included the side of the screen that currently hid the moving object during Occlusion 1A, Occlusion 1B, Occlusion 2A, and Occlusion 2B. Percentage scores were created by dividing the amount of time the infant looked at the half of the screen that currently hid the moving object by the time the infant looked at both halves of the screen. This reflects the percentage of time that the infant scanned the "correct" side of the screen (i.e., the side of the screen that hid the moving object).

No occlusion. Of primary interest during the no-occlusion portion of the event was the extent to which infants attended to the visible object moving to the side of the screen. Coding of this information was critical to interpretation of the entire occlusion event: If infants did not see the object that appeared to the left and the right of the screen, they would be unable to interpret the event (i.e., draw inferences about the number of objects present). Three time- and location-dependent AOIs were created: the moving visible object; the screen; and the opposite, and empty, side of the platform. As the event progressed, the visible object was seen to the left, the right, and then again to the left of the screen (see Figure 1A, Steps 1, 4, and 7). The proportion of time the infant spent tracking the visible object during the no-occlusion portion (time to object/time to all three AOIs) was calculated for each trial and used in data analysis.

Coding: Final phase. Three static AOIs were initially identified: the visible ball at the left end of the platform, the empty area behind the lowered screen at the center of the platform, and the empty area at the right end of the platform. A percentage score for each AOI was obtained by dividing the duration of looking to that AOI by the duration of looking to all three AOIs. This resulted in three percentage scores for each infant: the proportion of time spent looking at the ball at the left end of the platform, the proportion of time spent looking at the (empty) area behind the lowered screen, and the proportion of time spent looking at the right end of the platform. However, because infants spent less than 1% of their looking time attending to the right end of the platform, that location was eliminated as an AOI, so that only two AOIs remained (see Figure 2C).

Results

Data analyses were conducted on percentage duration of scanning to relevant AOIs during the initial and final phases of the test events. Raw looking times are included for reference (see Table 1). Some of the analyses reported next do not contain the full complement of infants included in the sample due to missing data points, either because an infant was not looking or because the eye tracker failed to capture the infant's eye during the time period of interest. Hence, degrees of freedom may vary. When missing, data points accounted for less than 6% of the total possible for the percentage-duration analyses.

Initial phase: Main analyses. For each of the analyses reported in this section, preliminary analyses including trial (1, 2, or 3) and occlusion interval (1 or 2) as within-subject factors were conducted. There were no significant main effects or interactions involving trial; hence the data were collapsed across trial for all analyses. There were no significant main effects or interactions involving occlusion interval except for one case (see the next section). In all other analyses the data were collapsed across occlusion interval.

Full occlusion. Infants' mean screen, look back, and anticipation percentage duration looking scores averaged across the three test trials were subjected to a mixed-model analysis of

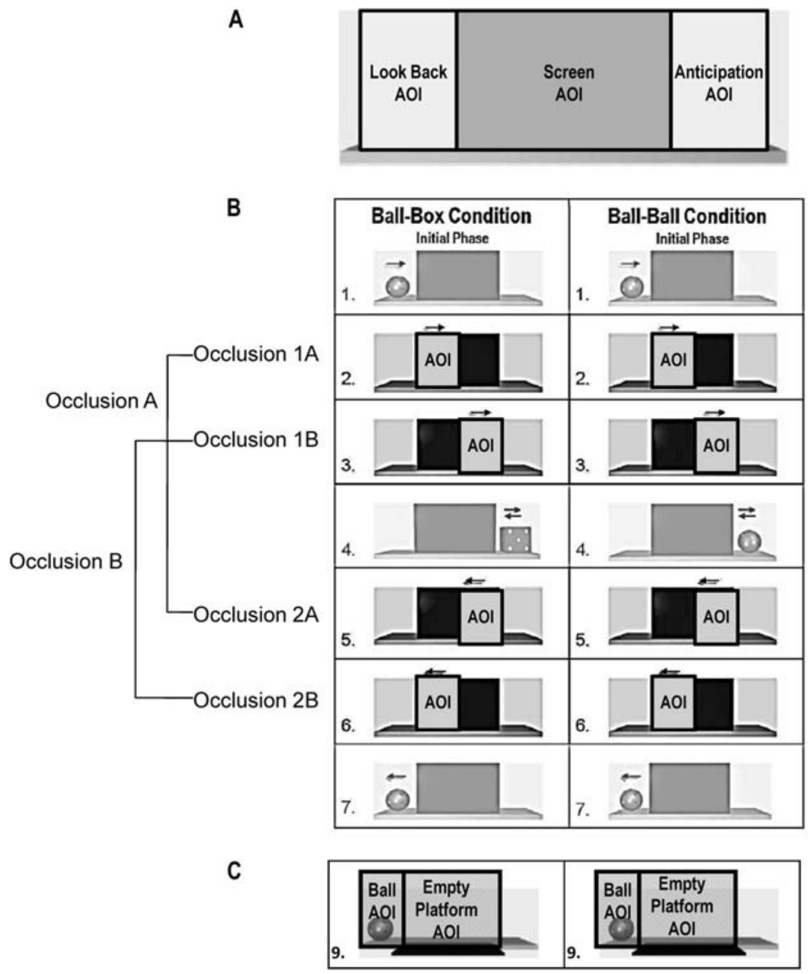

Figure 2. Areas of interest (AOIs) during the initial and final phases of the test event. A: During the initial phase of the test event, when the objects were fully occluded, three AOIs were identified: look back, looking to the screen, and anticipation. B: Of the time that infants spent looking to the screen during Occlusion 1 (A and B) and Occlusion 2 (A and B), the side of the screen that currently hid the moving occluded object was the AOI of interest. The location of this AOI moved over time (shifted right from Occlusion 1A to 1B and shifted left from Occlusion 2A and 2B). C: During the final phase of the test event, two AOIs were identified: the visible ball and the empty center of the platform behind the lowered screen.

variance (ANOVA) with AOI (screen, look back, anticipation) and occlusion interval (1 or 2) as within-subject factors and event condition (ball–box or ball–ball) and sex (male or female) as between-subjects factors. The main effect of AOI was significant, $F(2, 60) = 15.23$, $p < .001$, $\eta_p^2 = .34$, and the AOI × Occlusion Interval interaction was significant, $F(2, 60) = 21.02$, $p < .001$, $\eta_p^2 = .41$. There were no other significant main effects or interactions ($p < .05$). Follow-up comparisons revealed that the percentage of time that infants spent anticipating was greater during the second ($M = 51.89$, $SD = 29.58$) than the first ($M = 18.28$, $SD = 22.65$) occlusion interval, $t(33) = 6.80$, $p < .001$. In contrast, the percentage of time spent looking back was significantly greater during the first ($M = 26.70$, $SD = 28.06$) than the second ($M = 4.48$, $SD = 11.43$) occlusion interval, $t(33) = 4.70$ $p < .001$. The percentage of time infants spent looking at the screen did not differ significantly for Occlusion Interval 1 ($M = 55.02$, $SD = 30.14$) and 2 ($M = 43.40$, $SD = 28.85$), $t(33) = 1.98$, $p = 07$. In summary, as each trial progressed, infants were more likely to anticipate than look back when the objects were fully occluded.

Some researchers have reported anticipations in terms of the number of trajectories (of the total number of trajectories viewed) in which infants evidenced an anticipatory eye movement rather than duration of looking, as we have done here. For comparison purposes, we also performed these calculations on our data. Of the 176 possible occlusion intervals (infants included in the previously described analyses completed 88 trials, and each trial contained two occlusion intervals), infants made at least one anticipatory look on 76 (43%) of these intervals. This is consistent with the percentage of anticipations reported by other researchers with infants 6–10 months of age. Percentage of anticipations typically range from 25% to 50% (Gredebäck & von Hofsten, 2004; Rosander & von Hofsten, 2004; Woods, Wilcox, Armstrong, & Alexander, 2010), although under some conditions it can be higher (Johnson, Amso, & Slemmer., 2003). A mixed-model ANOVA

Table 1
Mean (and Standard Deviation) Duration of Looking (in Seconds) During the Test Event Averaged Across the Three Test Trials

Experiment, age, and condition	Initial phase: Full occlusion	Initial phase: No occlusion	Final phase: One-object display
Experiment 1: 9-month-olds			
Ball–box condition (n = 18)	1.74 (1.00)	3.52 (1.95)	1.65 (1.64)
Ball–ball condition (n = 18)	2.47 (0.96)	5.25 (2.13)	1.48 (1.17)
Total (N = 36)	2.11 (1.04)	4.39 (2.19)	1.57 (1.41)
Experiment 3: 4-month-olds			
Ball–box condition (n = 18)	1.51 (0.67)	4.44 (2.07)	1.49 (1.39)
Ball–ball condition (n = 16)	1.16 (0.73)	3.75 (2.34)	1.76 (1.64)
Total (N = 34)	1.34 (0.71)	4.11 (2.19)	1.62 (1.49)

Note. In the initial phase, the objects were fully occluded for 3.6 s and not occluded for 6.4 s. In the final phase, the one-object display was visible for 5 s. Boys and girls did not differ significantly in total duration of looking during the test events at either age group at $p < .05$.

was conducted with occlusion interval as a within-subject factor and sex and condition as between-subjects factors. There was a significant main effect of occlusion interval, $F(1, 76) = 5.90$, $p = .02$, $\eta_p^2 = .07$, with no other significant main effects or interactions. Infants were more likely to anticipate on the second (50%) than the first (33%) occlusion interval.

Infants' mean percentage of duration scanning of the correct side of the screen averaged across the three test trials was collapsed across occlusion interval to create two occlusion periods: Occlusion A (which includes Occlusion 1As and 2A) and Occlusion B (which includes Occlusions 1B and 2B). These data are displayed in Figure 3. The data were subjected to a mixed-model ANOVA with occlusion period (A or B) as the within-subject factor and event condition (ball–box or ball–ball) and sex (male or female) as between-subjects factors. The main effect of occlusion period was significant, $F(1, 28) = 5.69$, $p = .024$, $\eta_p^2 = .17$, and the Occlusion Period × Sex interaction was significant, $F(1, 28) = 11.71$, $p = .002$, $\eta_p^2 = .30$. No other main effects or interactions reached significance, all Fs$(1, 28) \leq 2$. Follow-up comparisons revealed that boys spent about the same percentage of time looking to the side of the screen that hid the moving object during Occlusion A (M = 49.16, SD = 29.46) and Occlusion B (M = 55.21, SD = 35.02), $t(15) < 1$. In contrast, the percentage of time that girls spent on the correct side of the screen was significantly greater during Occlusion A (M = 72.82, SD = 31.10) than during Occlusion B (M = 31.23, SD = 26.55), $t(15) = 4.50$, $p < .001$, Cohen's d = 1.41. Finally, during Occlusion B, boys spent a significantly greater percentage of time on the correct side of the screen than did girls, $t(31) = 2.39$ $p = .023$, Cohen's d = 0.83.

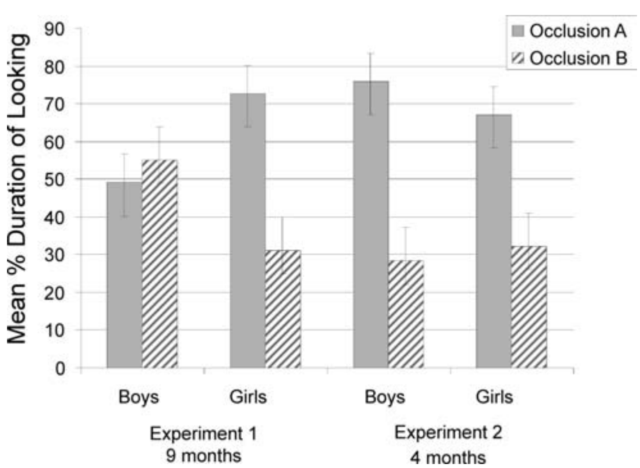

Figure 3. Mean percentage of duration looking (with standard error bars) to the moving areas of interests (AOIs) identified in Figure 2B for the 9-month-olds (Experiment 1) and 4-month-olds (Experiment 2). The effect of condition (ball–box or ball–ball) was not significant at either age, so data were collapsed across condition. Asterisks indicate comparisons that were significant ($p < .05$).

These results suggest that the boys shifted visual attention from one side of the screen to the other during the occlusion interval, scanning both sides of the screen during the occlusion sequence. In contrast, girls focused attention on the side of the screen behind which the object last disappeared, seldom shifting attention to the other side of the screen as the event progressed. However, it is possible that boys and girls were equally likely to shift attention (i.e., scan both sides of the screen) but that boys were more likely than girls to divide their looking time equally as they did so. To test this hypothesis, we assessed infants' scanning patterns as the object moved left to right (Occlusion 1As and 1B) or right to left (Occlusion 2As and 2B) behind the screen. Of the 164 possible Occlusion A intervals (infants included in the previously described analyses completed 82 trials, and each trial contained two "A" occlusion intervals), infants contributed scanning data for 97 of these intervals (51 for boys and 46 for girls). Of the 164 possible Occlusion B intervals (infants included in the previously described analyses completed a total of 82 trials, and each trial contained two "B" occlusion intervals), infants contributed scanning data for 94 of these (46 for boys and 48 for girls). (The number of trials included in this analysis is lower than that for anticipations because infants were included here only if they looked at the screen during both Occlusion A and Occlusion B for each occlusion interval [1 and 2]. This was not a prerequisite for inclusion in the analysis of anticipations, where trials were included if infants looked sometime during Occlusions A and B.) First, we assessed the number of Occlusion A and Occlusion B intervals in which the infant's first look was to the correct (compared with incorrect) side of the screen. If the infant were tracking the object through occlusion, we would expect the infant's first look of each occlusion interval to be to the correct side of the screen. For Occlusion A, boys directed 44 (of their 51) first looks to the correct side of the screen and girls directed 36 (of their 46) first looks to the correct side of the screen (binomial probabilities $p < .001$). For Occlusion B, boys directed 28 (of 46) first looks to the correct side of the screen (binomial probability $p > .05$), whereas girls directed only 14 (of 48) first looks to the correct side of the screen (binomial probability $p = .002$). The girls infrequently looked at the correct side of the screen. On Occlusion A, when the object had just disappeared behind the screen, both boys and girls directed their attention to the correct side of the screen. However, on Occlusion B, when the moving object had changed location behind the screen, the majority of boys' looks were to the correct side of the screen. In contrast, most girls remained focused on the side of the screen behind which the object last disappeared. To assess the extent to which infants eventually shifted attention to the correct side of the screen during the occlusion intervals, we counted the number of Occlusion A and Occlusion B intervals in which the infant looked to the correct side of the screen at least once. The boys looked to the correct side of the screen at least once on 47 of 51 Occlusion A intervals and 34 of 46 Occlusion B intervals (binomial probabilities $p < .001$). The girls looked at the correct side of the screen at least once on 40 of 46 Occlusion A intervals (binomial probability $p < .001$) and 26 of 48 Occlusion B intervals (binomial probability $p = .097$). These data indicate that even though the majority of the girls' first looks were to the incorrect side of the screen during Occlusion B, they eventually shifted attention to the correct side of the screen, for at least a brief period of time, on many of those occlusion intervals. However, the number of occlusion intervals on which this occurred did not differ significantly from chance.

Infants were also categorized as a whole-screen (as opposed to part-screen) scanner if they scanned both sides of the screen on at least half of the occlusion intervals for which they contributed data. During the Occlusion A interval, 13 of the 16 boys (binomial probability $p = .012$) but only nine of 17 girls (binomial probability $p > .05$) were categorized as whole-screen scanners. During Occlusion B interval, 12 of the 16 boys (binomial probability $p = .028$) but only nine of the 17 girls (binomial probability $p > .05$) were categorized as whole-screen scanners. Finally, one might be concerned that boys were more likely than girls to scan both sides of the screen because they were more active in their scanning behavior. It is possible that infants who are more active in visual scanning are more likely to eventually venture to the other side of the screen. To test this possibility, we counted the number of times infants moved their gaze during Occlusion A and B. A mixed-model ANOVA was conducted with occlusion interval (A or B) as the within-subject factor and sex as the between-subjects factor. The main effect of occlusion interval, $F(1, 34) = 2.59$, $p > .05$, and sex, $F(1, 34) < 1$, and their interaction, $F(1, 34) < 1$, were not significant. The boys ($M = 2.34$, $SD = 1.22$) and girls ($M = 2.21$, $SD = 0.59$) shifted their gaze about the same number of times during the occlusion intervals. Collectively, the scanning data indicate that boys were more likely than girls to scan both sides of the screen during the occlusion interval, just as they were more likely than girls to divide duration of looking to both sides of the screen. In contrast, girls primarily scanned the side of the screen behind which an object last disappeared, seldom shifting attention to the other side of the screen as the occlusion interval progressed. This finding could not be explained by more active or frequent scanning by boys than girls.

No occlusion. The mean percentage of time infants spent looking at the moving visible object averaged across the three test trials was subjected to an ANOVA with event condition (ball–box or ball–ball) and sex (male or female) as between-subjects factors. The main effects of event condition and sex, $Fs(1, 32) < 1.5$, and the Event Condition × Sex interaction, $F(1, 32) = 3.52$, $p = .077$, were not significant. The groups did not differ significantly in the percentage of time they spent attending to the moving visible object during the no-occlusion portion of the event sequence (ball–box condition, $M = 71.85$, $SD = 17.95$, and ball–ball condition, $M = 69.32$, $SD = 15.26$).

Final phase. The mean percentage of time infants spent looking at the visible ball and the empty area behind the lowered screen averaged across the three test trials (see Figure 4A) was subjected to a mixed-model ANOVA with AOI (visible ball and center of platform) as the within-subject factor and event condition (ball–box or ball–ball) and sex (male or female) as the between-subjects factors. The main effect of AOI was significant, $F(1, 32) = 31.77$, $p < .001$, $\eta_p^2 = .50$. The main effects of event condition, $F(1, 32) < 1$, and of sex, $F(1, 32) = 2.14$, $p = .153$, were not significant. In addition, all of the two-way interactions (Condition × Sex, AOI × Condition, AOI × Sex) were not significant, $Fs(1, 32) \leq 1.5$. The three-way AOI × Condition × Sex interaction was significant, $F(1, 32) = 6.06$, $p = .019$, $\eta_p^2 = .16$.

Follow-up analyses were conducted for each condition separately using a mixed-model 2 (AOI) × 2 (sex) ANOVA. For the ball–box condition, the main effect of AOI, $F(1, 16) = 12.61$, $p = .003$, $\eta_p^2 = .44$, and the AOI × Sex interaction, $F(1, 16) = 5.43$, $p = .033$, $\eta_p^2 = .25$, were significant. The boys spent about the same percentage of time attending to the visible ball ($M = 57.60$, $SD = 36.94$) and the center of the platform ($M = 41.79$, $SD = 37.37$), whereas the girls spent a greater percentage of time attending to the visible ball ($M = 87.97$, $SD = 11.26$), rarely shifting attention to the center of the platform ($M = 11.87$, $SD = 11.25$). For the ball–ball condition, only the main effect of AOI, $F(1, 16) = 21.54$, $p < .001$, $\eta_p^2 = .57$, was significant. Both boys and girls attended primarily to the visible ball ($M = 72.67$, $SD = 25.95$), only occasionally shifting attention to the empty center of the platform ($M = 26.86$, $SD = 20.79$).

Initial and final phases: Correlation analyses. As just reported, boys and girls demonstrated different patterns of scanning during the occlusion events, with boys more likely than girls to scan both sides of the occluding screen. To assess whether scanning of the occluding screen predicts scanning of the final display, correlations were obtained between percentage of duration looking to the correct side of the screen during Occlusion A and Occlusion B (initial phase) and percentage of duration looking to the ball and the center of the platform (final phase). Correlation analyses were computed for each condition separately because scanning patterns observed during the final phase differed for the two conditions. The results revealed that in the ball–box condition, those infants who spent a greater percentage of time looking at the side of the screen that hid the moving object during Occlusion B were significantly less likely to scan the visible ball and more likely to scan

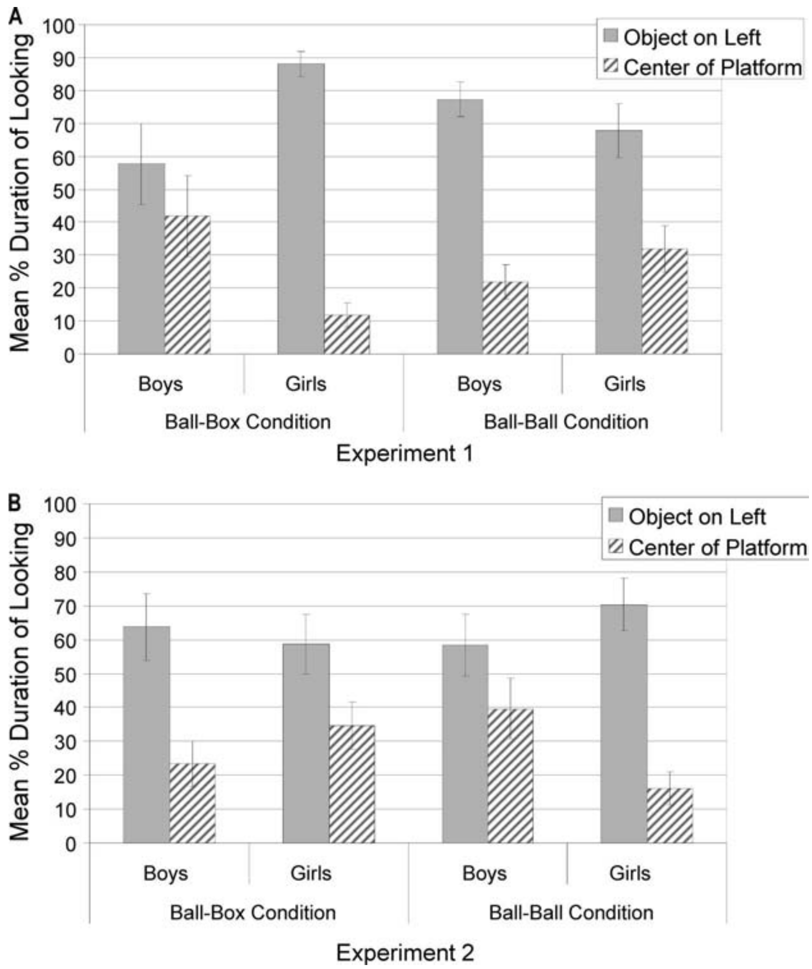

Figure 4. A: Mean percentage of duration looking (with standard error bars) to the two areas of interest (AOIs) identified in Figure 2C for the 9-month-olds (Experiment 1). B: Mean percentage of duration looking (with standard error bars) to the two AOIs identified in Figure 2C for the 4-month-olds (Experiment 2). Asterisks indicate comparisons that were significant ($p < .05$).

the empty center of the platform during the final phase (see Table 2).That is, those infants who attempted to track the trajectory of the objects through occlusion, particularly as the object moved from one half of the screen to the other, were more likely to visually search for a second object at the center of the platform when the screen was lowered. In the ball–ball condition, looking patterns during the initial and final phases were not significantly correlated. Finally, the magnitude of the correlation between Occlusion B (initial phase) and the ball at left (final phase) obtained in the ball–box condition (–.618) differed significantly from that obtained in the ball–ball condition (.311; Fisher's difference between the correlations, $p = .007$). This outcome indicated that the relation between scan patterns observed in the initial and final phases differed for the two conditions.

Discussion

Three main findings emerged in Experiment 1. First, sex differences were observed in infants' scanning of the occluder during the initial phase of the test event. Regardless of whether infants viewed a ball–box or ball–ball event, boys scanned both sides of the screen during the occlusion interval, spending about an equal amount of time scanning the half of the screen that currently hid the moving object and the other half of the screen. In contrast, girls fixated on the side of the screen behind which an object had most recently disappeared, rarely shifting attention to the other half of the screen even as the event progressed. These results suggest that the boys, but not the girls, attempted to track the trajectory of the objects as they moved behind the screen. Sex differences were specific to visual scanning of the screen during the occlusion interval. Boys and girls did not differ reliably in the total percentage of time they spent looking at the screen, compared with looking back or anticipating, when the objects were occluded. In addition, when the objects were visible, boys and girls did not differ reliably in the percentage of time they spent attending to (tracking) the moving object.

Second, in the ball–box condition boys and girls evidenced different patterns of scanning to the final display. Boys scanned the visible ball and the center of the platform about equally, visually

Table 2
Correlations (r) Between Percentage of Duration Looking to the Side of the Screen That Hid the Moving Object During Occlusions A and B (Initial Phase) and Percentage of Duration Looking to the Ball and the Center of the Platform (Final Phase)

Experiment, age, and condition	Occlusion A	Occlusion B
Experiment 1: 9-month-olds		
Ball–box condition ($n = 16$)		
Ball at left	.344	–.618*
Center of platform	–.341	.611*
Ball–ball condition ($n = 17$)		
Ball at left	–.083	.311
Center of platform	.083	–.342
Experiment 3: 4-month-olds		
Ball–box condition ($n = 17$)		
Ball at left	.148	.546*
Center of platform	–.193	–.398
Ball–ball condition ($n = 15$)		
Ball at left	–.023	.240
Center of platform	–.167	–.253

* $p < .025$.

searching the area behind the lowered screen. In contrast, girls attended primarily to the visible ball. These data suggest that boys, but not girls, expected a second object to be revealed when the screen was lowered and found the one-object display unexpected. That is, boys found their representation of the ball–box event (two objects) inconsistent with the structure of the final one-object display (one object). In the ball–ball condition, both boys and girls scanned the visible ball, rarely shifting attention to the center of the platform. Apparently both boys and girls interpreted the ball–ball event as involving a single object that moved back and forth across the platform and found their representation of the ball–ball event (one object) consistent with the structure of the final one-ball display (one object).

Third, and most telling, was that visual scanning of the screen during the occlusion interval predicted visual scanning of the final display in the ball–box condition. The ball–box infants who scanned both sides of the screen during Occlusion B (the second half of the occlusion interval, when the object had moved position behind the screen) were more likely to look to the center of the platform for the missing box and less likely to focus on the visible ball when the screen was lowered. These results suggest that those infants who tracked the trajectory of the ball and box during the occlusion interval, shifting attention from one side of the occluding screen to the other as the event progressed, were more likely to extract the simple structure of the occlusion event. Once the simple structure of the occlusion event was extracted, infants could compare this structure (i.e., two objects) with that of the final display (i.e., one object). However, when infants failed to track the objects' trajectories they were unable to extract the simple structure of the occlusion event, making interpretation of the final display difficult.

One might question why, in the ball–ball condition, scanning of the screen during the occlusion interval did not predict scanning of the final display. One possible explanation has to do with the complexity of the objects' trajectories (see Figure 1B). In the ball–ball event, a single object moved back and forth behind the screen. The trajectory of the object, even when it was occluded, was very simple: It moved on a single, unaltered path. Extrapolating the trajectory of the ball in the ball–ball event was a relatively easy task for the infants and, hence, did not require focused tracking of the object's trajectory when it was occluded. In contrast, in the ball–box event two numerically distinct objects moved on different paths, each object starting and stopping, and reversing, its path of motion behind the screen. Only when the event structure was more complicated, and tracking behavior was engaged, did scanning during the occlusion sequence predict looking to the final display.

Experiment 2

Experiment 2 investigated whether the sex differences observed in older infants would be observed in younger infants. Infants at ages 3–4 months, with a mean age of 4 months, were tested using a protocol identical to that of Experiment 1. It was expected that 4-month-old boys and girls would show the same pattern of visual behavior as did the 9-month-old girls. However, it is possible that sex differences would be observed in some measures (e.g., scanning of the screen during occlusion) but not others (e.g., scanning of the final display) in the younger infants.

Method

Participants. Thirty-four healthy, term infants participated (18 male, 16 female; M age = 4 months 1 day, range = 3 months 1 day to 4 months 26 days). Thirty-three parents reported their infant's race/ethnicity: Caucasian ($n = 21$), Hispanic ($n = 4$), Asian ($n = 4$), Black ($n = 2$), and Native American ($n = 2$). Two additional infants were tested but eliminated from analyses because of failure to look at the display once testing began. Infants were pseudorandomly assigned to one of two groups: ball–box (male $n = 10$, M_{age} = 4 months 1 day, range = 3 months 5 days to 4 months 25 days; and female $n = 8$, M_{age} = 4 months 1 days, range = 3 months 12 days to 4 months 22 days) and ball–ball (male $n = 8$, M_{age} = 3 months 27 days, range = 3 months 1 day to 4 months 22 days; and female $n = 8$, M_{age} = 4 months 2 days, range = 3 months 4 days to 4 months 26 days).

Experimental set-up, procedure, events, and coding. The experimental set-up, procedure, test events, and data coding were identical to those of Experiment 1.

Results

Initial phase: Main analyses. For each of the analyses reported in this section, preliminary analyses including trial (1, 2, or 3) and occlusion interval (1 or 2) as within-subject factors were conducted. There were no significant main effects or interactions involving trial; hence the data were collapsed across trial for all analyses. There were no significant main effects or interactions involving occlusion interval except for one case (see the analysis in the next section). In all other analyses the data were collapsed across occlusion interval.

Full occlusion. Infants' mean screen, look back, and anticipation percentage of duration looking scores averaged across the three test trials (see Figure 4A) were subjected to a mixed-model ANOVA with AOI (screen, look back, anticipation) and occlusion interval (1 or 2) as within-subject factors and event condition (ball–box or ball–ball) and sex (male or female) as between-subjects factors. The main effect of AOI was significant, $F(2, 58) = 19.28$, $p < .001$, $\eta_p^2 = .40$, and the AOI × Trajectory interaction was significant, $F(2, 58) = 14.14$, $p < .001$, $\eta_p^2 = .33$. There were no other significant main effects or interactions. Follow-up comparisons revealed that the percentage of time that infants spent anticipating was greater during the second ($M = 45.38$, $SD = 29.70$) than first ($M = 14.80$, $SD = 24.36$) occlusion interval, $t(32) = 4.72$, $p < .001$. In contrast, the percentage of time that they spent looking back was significantly greater during the first ($M = 27.17$, $SD = 12.34$) than second ($M = 6.73$, $SD = 12.34$), occlusion interval, $t(32) = 4.66$, $p < .001$. The percentage of time that infants spent looking at the screen did not differ significantly for Occlusion Interval 1 ($M = 58.92$, $SD = 29.66$) and 2 ($M = 46.38$, $SD = 29.85$), $t(32) = 1.81$, $p = 08$. In summary, like the older infants the younger infants were more likely to anticipate and less likely to look back as each trial progressed.

We also calculated the number of trajectories (of the total number of trajectories viewed) in which infants evidenced an anticipatory eye movement. Of the 178 possible occlusion intervals (infants included in the previously described analyses completed 89 trials, and each trial contained two occlusion intervals), infants made at least one anticipatory look on 82 (46%) of these intervals. A mixed-model ANOVA was conducted with occlusion interval as a within-subject factor and sex and condition as between-subjects factors. There was a significant main effect of occlusion interval, $F(1, 77) = 25.23$, $p < .001$, $\eta_p^2 = .25$, with no other significant main effects or interactions. Like the older infants, the younger infants were more likely to anticipate on the second (64%) than the first (30%) occlusion interval.

Finally, there was reason to suspect that we might find age-related changes for anticipatory looking. Johnson et al. (2003) reported an increase between 4 months and 6 months in the proportion of time that infants exhibit predictive looking during a repeating occlusion sequence (they averaged data across occlusion interval and trial). Rosander and von Hofsten (2004) analyzed the proportion of anticipatory looking during a repeating occlusion sequence by trial and occlusion interval (the number of times within a trial that the object had been occluded) and reported age-related changes in predictive looking within trials. More specifically, 3- and 4-month-olds were more likely than 5-month-olds to show an increase in predictive looking as a trial progressed, even though they did not evidence an increase in the number of anticipations across trials. To assess whether the younger and older infants tested here differed in anticipatory looking, a mixed-model ANOVA was conducted on percentage of anticipations, with age (young or old) as the between-subjects factor and occlusion interval (1 or 2) as the within-subject factor. Trial was not included in the analysis, because previous analyses indicated that trial did not account for a significant proportion of the variance in predictive looking at either age. The main effect of occlusion interval was significant, $F(1, 175) = 29.38$, $p < .001$, $\eta_p^2 = .14$, as was the Occlusion Interval × Age interaction, $F(1, 175) = 4.03$, $p = .046$, $\eta_p^2 = .02$. The main effect of age was not significant, $F(1, 175) < 1$. Follow-up comparison revealed that, whereas 4- and 9-month-olds made about the same percentage of anticipations during the first occlusion interval, $t(175) < 1$, the older infants made more anticipations than did the younger infants during the second occlusion interval, $t(175) = 1.90$, $p = 06$, although the effect did not reach significance.

Infants' mean percentage of duration looking at the correct side of the screen, which was the side of the screen that hid the moving object (see Figure 3) was subjected to a mixed-model ANOVA with occlusion period (A or B) as the within-subject factor and event condition (ball–box or ball–ball) and sex (male or female) as between-subjects factors. The main effect of occlusion period was significant, $F(1, 28) = 33.42$, $p < .001$, $\eta_p^2 = .54$. No other main effects or interactions reached significance, all $Fs(1, 28) < 1$ except Occlusion Period × Event Condition, $F(1, 28) = 2.59$, $p = .12$. The percentage of time that infants (boys and girls) spent looking to the side of the screen that hid the moving object was greater during Occlusion A ($M = 71.83$, $SD = 32.41$) than during Occlusion B ($M = 30.20$, $SD = 25.83$). At 4 months of age, boys and girls focused attention on the side of the screen behind which the object last disappeared, failing to shift their duration of attention to the other side of the screen as the event progressed. This is the same pattern of results found with the older girls in Experiment 1.

As in Experiment 1, we also assessed infants' scanning patterns as the object moved from left to right (Occlusions 1A and 1B) or from right to left (Occlusions 2A and 2B) behind the screen. Of the 164 possible Occlusion A intervals (infants included in the previously described analyses completed 82 trials, and each trial contained two "A" occlusion intervals), infants contributed scanning data for 99 of these intervals (48 for boys and 51 for girls). Of the 164 possible Occlusion B intervals (infants included in the analyses previously described completed a total of 82 trials, and each trial contained two "B" occlusion intervals), infants contributed scanning data for 113 of these (54 for boys and 59 for girls). First, we counted the number of Occlusion A and Occlusion B intervals in which the infant's first look was to the correct (compared with incorrect) side of the screen. For Occlusion A, boys directed 40 (of their 48) first looks to the correct side of the screen and girls directed 43 (of their 51) first looks to the correct side of the screen (binomial probabilities $p < .001$). For Occlusion B, boys directed 16 (of 54) first looks to the correct side of the screen (binomial probability $p = .001$) and girls directed 20 (of 59) first looks to the correct side of the screen (binomial probability $p = .005$). On Occlusion A, when the object had just disappeared behind the screen, both boys and girls scanned predominantly the correct side of the screen. On Occlusion B, as the moving object changed location behind the screen, both boys and girls scanned predominantly the incorrect side of the screen. Hence, the 4-month-old boys and girls of Experiment 2 performed like the 9-month-old girls of Experiment 1: They failed to immediately shift their attention to the location of the moving object during the second half of the occlusion interval. To assess the extent to which infants eventually shifted attention to the correct side of the screen, we assessed the number of Occlusion A and Occlusion B intervals in which the infant looked to the correct side of the screen at least once. For Occlusion A, boys looked to the correct side of the screen at least once on 43 (of 48 possible) intervals and girls looked at least once on 48 (of 51 possible) intervals (binomial probabilities $p < .001$). For Occlusion B, boys looked to the correct side of the screen at least once on 28 (of 54 possible) intervals and girls on 31 (of 59 possible) intervals (binomial probabilities $p > .05$). These data indicate that even though the majority of infants (boys and girls) first looked to the incorrect side of the screen during Occlusion B, at least some of these infants eventually looked to the correct side of the screen. However, the number of infants that showed this behavior did not differ significantly from chance. Finally, infants were categorized as whole-screen scanner (as opposed to part-screen scanner) if they scanned both sides of the screen on at least half of the occlusion intervals for which they contributed data. During the Occlusion A interval, eight of 17 boys and eight of 16 girls (binomial probabilities $p > .05$) were categorized as whole-screen scanners. During Occlusion B interval, seven of 17 boys and six of 16 girls (binomial probabilities $p > .05$) were categorized as whole-screen scanners. To test whether boys were more active scanners than girls, we counted the number of times infants moved their gaze during Occlusions A and B. A mixed-model ANOVA was conducted with occlusion interval (A or B) as the within-subject factor and sex as the between-subjects factor. The main effect of occlusion interval, $F(1, 32) = 3.69$, $p > .05$, and sex, $F(1, 32) < 1$, and their interaction, $F(1, 32) < 1$, were not significant. The boys ($M = 2.44$, $SD = 0.85$) and girls ($M = 2.45$, $SD = 0.87$) shifted their gaze about the same number of times during the occlusion intervals.

No occlusion. The mean percentage of time that infants spent looking at the moving visible object was subjected to an ANOVA with event condition (ball–box or ball–ball) and sex (male or female) as between-subjects factors. The main effects of event condition and sex, $Fs(1, 30) < 1$, and the Event Condition $\times$ Sex interaction, $F(1, 30) = 3.31$, $p = .08$, were not significant. The groups did not differ reliably in the percentage of time they spent attending to the moving visible object during the no-occlusion portion of the event sequence (ball–box condition, $M = 45.83$, $SD = 19.16$, and ball–ball condition, $M = 46.79$, $SD = 15.68$). Note that the 4-month-olds spent a smaller percentage of their time tracking the visible object than did the 9-month-olds. Follow-up analysis revealed that, whereas the absolute amount of time the 4- and 9-month-olds spent looking during the nonocclusion portion of the event sequence did not differ reliably (see Table 1), $F(1, 68) < 1$, the 9-month-olds (grand $M = 69.32$, $SD = 15.26$) spent a significantly greater percentage of this time looking at the visible object than did the 4-month-olds (grand $M = 46.28$, $SD = 17.35$), $F(1, 68) = 34.91$, $p < .001$, $\eta_p^2 = .34$. This means that the younger infants spent more time than the older infants did scanning other components of the visual display, which included the upright screen and the empty platform to the other side of the screen.

Final phase. The mean percentage of time that infants spent looking at the visible ball and the empty area behind the lowered screen (see Figure 4B) was subjected to a mixed-model ANOVA with AOI (visible ball and center of platform) as the within-subject factor and event condition (ball–box or ball–ball) and sex (male or female) as the between-subjects factors. The main effect of AOI was significant, $F(1, 29) = 18.89$, $p < .001$, $\eta_p^2 = .39$. The main effects of event condition and sex were not significant, $Fs(1, 29) < 1$. In addition, none of the two-way interactions, $Fs(1, 29) < 1.5$, nor the three-way interaction, $F(1, 29) = 2.57$, $p = .12$, were significant. These results indicate that the infants spent a greater percentage of their time attending to the visible ball ($M = 62.56$, $SD = 25.72$) than the center of the platform ($M = 28.63$, $SD = 23.04$) regardless of event condition or sex. This is the same pattern of results found with the 9-month-old girls in Experiment 1.

Initial and final phases: Correlation analyses. To assess whether scanning of the occluding screen predicts scanning of the final display, correlations were obtained between percentage of duration looking to the correct side of the screen during Occlusion A and Occlusion B (initial phase) and percentage of duration looking to the ball and the center of the platform (final phase). To be consistent with Experiment 1, correlation analyses were computed for each condition separately (see Table 1). One correlation reached significance: In the ball–box condition, those infants who spent a greater percentage of time looking at the side of the screen that hid the moving object during Occlusion B were more likely to scan the visible ball during the final phase. However, the magnitude of this correlation did not differ significantly from that obtained in the ball–ball condition (.546 vs. .240, Fisher's difference between the correlations, $p = .347$), and overall, the correlations obtained in the ball–box condition were similar to those obtained in the ball–ball condition.

Discussion

Experiment 2 investigated 4-month-olds' visual scanning during the event-mapping task used with the 9-month-olds of Experiment 1. Two main findings emerged. First, during the occlusion interval of the initial phase of the event sequence, both boys and girls fixated on the side of the screen behind which an object had most recently disappeared, seldom shifting attention to the other half of the screen as the event progressed. These results are identical to those obtained with the older girls in Experiment 1 and suggest that at the 4-month-old boys and girls, like the 9-month-old girls, failed to track the trajectory of the objects as they moved behind the screen. Second, during the final phase of the test event, when the occluding screen was lowered, both boys and girls in the ball–box condition attended primarily to the visible ball at the left side of the platform, seldom shifting attention to the empty area at the center of the platform. These results suggest that the younger boys and girls, like the older girls, failed to detect an inconsistency between the structure of the ball–box sequence (two objects) and the structure of the final display (one object). In summary, the pattern of eye-tracking results obtained with the 4-month-old boys and girls was similar to that obtained with the 9-month-old girls, suggesting that the sex differences observed in Experiment 1 emerge sometime between 4 and 9 months of age.

One aspect of looking behavior that did not vary by sex was infants' distribution of attention when the object was occluded. The 4-month-olds, like the 9-month-olds, exhibited more looks back than anticipations during the first occlusion interval (as the event moved left to right across the platform) and more anticipations than looks back during the second occlusion interval (when the event reversed direction and moved right to left). These findings are consistent with previous reports that experience with an occlusion sequence can lead to greater anticipatory looking within a trial, even though this does not necessarily carry forward across trials (Rosander & von Hofsten, 2004). In addition, a comparison of anticipatory looking across the two age groups suggests that the older infants benefited more from this experience than did the younger infants (i.e., the older infants exhibited a greater percentage of anticipatory looks than did the younger infants during the second occlusion interval). This finding is consistent with previous reports that with age infants are more likely to benefit from previous experience with an occlusion interval within a trial (Rosander & von Hofsten, 2004). Caution in warranted, however, in interpretation of our data because the effect was weak. We suspect that if infants had seen more cycles of the event during each trial, which is typically the case in studies of anticipatory looking, the age effect would have been stronger.

Finally, it is important to recognize that visual tracking of objects, and in particular anticipatory looking, is influenced by a number of factors. For example, events involving objects that move more quickly behind occluders that are narrower typically elicit more anticipations than do those involving slower moving objects and wider occluders (Gredebäck & von Hofsten, 2004; Rosander & von Hofsten, 2004). In addition, events in which objects follow more complex or unpredictable paths tend to elicit fewer anticipatory looks than do those involving simple, predictable paths (Canfield, Smith, Brezsnyak, & Snow, 1997; Johnson et al., 2003). There is also evidence that infants are more proficient at tracking horizontal than vertical trajectories (Grönqvist, Gredebäck, & von Hofsten, 2006). A full understanding of infants' anticipatory looking during occlusion events, as well as their ability to track objects through occlusion, depends on systematic investigation of these factors.

General Discussion

In recent years a number of studies have reported sex differences in infants' performance on event-mapping tasks (Schweinle & Wilcox, 2004; Wilcox, 2003, 2007). The present research explored the underlying basis for these sex differences. Two studies were conducted in which 9-month-olds' (Experiment 1) and 4-month-olds' (Experiment 2) gaze patterns were assessed, using eye-tracking technology, during the initial occlusion phase and the final no-occlusion phase of an event-mapping task. An intriguing pattern of results emerged.

First, at 9 months sex differences were observed in patterns of looking during the occlusion sequence. Boys were more likely than girls to scan both sides of the screen when the objects were fully occluded, shifting attention as the objects moved left to right (or right to left) behind the screen. In contrast, girls focused attention on the side of the screen behind which an object most recently disappeared, rarely shifting attention as the occlusion interval, and the location of the moving object, progressed. Sex differences were not observed in visual scanning of other components of the occlusion sequence. For example, boys and girls did not differ in the percentage of time they spent attending to the moving object when it was visible. Boys and girls also did not differ in the percentage of time they spent attending to the occluder (as a whole), looking back to where an object was last seen, or anticipating where an object would next appear. In short, boys and girls did not differ, more generally, in visual scanning of the dynamic display. They differed, specifically, in their pattern of visual scanning to one component of the dynamic display: the two halves of the screen when the objects were fully occluded behind the screen. These data suggest that the boys and girls engaged in different processes during the occlusion interval (Hayoe, 2004). Finally, sex differences in scanning of the occlusion sequence observed at 9 months were not observed at 4 months. At 4 months the boys and girls performed like the 9-month-old girls, indicating that this difference emerges sometime between 4 and 9 months.

Second, at 9 months boys were more likely than girls to detect an inconsistency between the number of objects involved in the occlusion sequence and the number of objects revealed when the screen was lowered. After viewing the ball–box event sequence, boys were more likely to visually search for the missing box at the center of the platform when the screen was lowered. This finding is consistent with those obtained in violation-of-expectation tasks, in which boys are more likely than girls to look longer at a one-ball display after viewing a ball–box event (Wilcox, 2003, 2007). Again, sex differences were not observed at 4 months: Both boys and girls performed like the 9-month-old girls. Third, and most intriguing, was that in the older group, visual scanning of the initial occlusion sequence was related to visual scanning of the final one-ball display. Those infants who attended to the side of the screen that currently hid the moving object during the ball–box occlusion sequence, particularly as the event progressed (i.e., during Occlusion B), were significantly more likely to scan the center of the platform, searching for the missing box, during the final one-ball display. This suggests that the processes in which infants engaged during the initial ball–box occlusion sequence were related to their ability to interpret the final one-ball display.

What were the processes in which infants were engaged, and how were these related to successful event mapping? One explanation for these results, and the one alluded to earlier, is the following: When viewing occlusion events, infants draw on multiple sources of information to individuate the objects. For example, in the case of the ball–box event featural information suggests that the object seen to the left of the screen (a green sphere) is distinct from that seen to the right of the screen (a red cube). Given that featural information suggests two objects and that "two" is consistent with the spatiotemporal parameters of the event (the screen is sufficiently wide to occlude both objects), infants interpret the event as involving two objects. (Under some circumstances infants might use other sources of information about the objects, such as the category to which they belong [Xu, 2002], to determine whether they constitute distinct individuals, but this is not relevant to the present discussion.) Next, and this is where male and female infants differ in their ability, infants must extract a summary outline of the event. In the case of the ball–box event it is something akin to "object A moves on a trajectory behind the left side of the screen, and object B on a trajectory behind the right." Boys, who more easily than girls extract occluded trajectories, are able to identify the two objects' trajectories and hence scan both sides of the screen during occlusion sequences, shifting their attention as the position of the moving object changes behind the screen. Once the simple structure of the ball–box event is identified, boys compare this representational structure (two objects) with that of the final display (one object) and find the two structures incompatible. That is why they visually search the area behind the lowered screen for a second object. If the initial and final event are of the same event category, and comparison across event structures is not necessary, then sex differences are not observed (Wilcox & Chapa, 2002).

The fact that boys also scan both sides of the screen during the ball–ball event suggests that they attempt to follow occluded motion regardless of whether the motion pattern involves one object trajectory or two object trajectories. Why, then, was scanning of the screen during the ball–ball occlusion sequence not related to looking to the final display? When the trajectory is simple, infants do not need to follow occluded motion to extract the structure of the event—even though boys still do so. In fact, when two object emergences fall on opposite ends of a single occluded horizontal path, and there is no direct evidence contradicting the presence of a single object (the object seen to the left and right of the screen are identical in appearance), the path of motion between the two emergences does not need to be extrapolated. Infants can "connect the dots" between the two emergences without necessarily drawing inferences about the occluded trajectory. Hence, both boys and girls represent the ball–ball event as involving a single object—but they form this representation through different processes. Of course, this is a post hoc explanation of the results that needs to be tested.

There is an alternative interpretation of the data to be considered. According to a recent model of physical reasoning (Baillargeon et al., in press), infants' interpretations of physical events are influenced by two distinct sources of information: general and specific. General information is primary and includes information about the basic structure of the event, such as the spatiotemporal properties of the objects and the category (ontological, functional, taxonomic) to which the objects belong. In contrast, specific information includes details about the objects, such as their shape or color. In the case of the ball–box event, the general structure of the event—self-propelled, nonagentive motion to both sides of the screen—suggests a single object oscillating behind the screen. In contrast, specific information—one object appears as a green sphere and the other as a red cube—suggests the presence of two objects. These two sources of information are held separately in different "layers" of the representation. In order to form an integrated representation of the occlusion sequence that infants can carry forward and compare with the final display, infants must resolve the conflict between the number of objects suggested by general information (referred to as the structural layer) and the number suggested by specific information (referred to as the variable layer).

According to this viewpoint, sex differences in performance on event-mapping tasks such as the one used in the present experiment arise because girls are unable to form an integrated representation of the occlusion sequence. This occurs because girls have difficulty representing general information about the event (e.g., the spatiotemporal properties of the objects or whether the objects belong to different ontological categories) or because they are unable to perform the computations necessary to integrate general and specific information. The fact that boys and girls differ in their scanning of both events (ball–box and ball–ball) suggests the latter—that girls have more difficulty than boys representing the basic structure of the event. (It is unlikely that boys and girls differ in their ability to detect specific information. There is evidence from tasks that do not require event mapping [Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b] that boys and girls perceive a ball–box event as involving two objects). Only when infants have successfully resolved the conflict between general and specific information are they able to detect a violation in the final display. The reason there is no correlation between scanning of the initial occlusion sequence and scanning of the final display in the ball–ball condition is because there is no conflict between the number of objects specified by the general structure and the number specified by object features: Both suggest a single object. When there is no conflict, both boys and girls are able to form an integrated representation to compare to the final display.

The main difference between these two explanations is that the first suggests that infants integrate multiple sources of information to interpret the event and then extract the simple structure of the event (i.e., the number of objects and their spatiotemporal coordinates). Boys and girls differ in their ability to extract the simple structure, which depends on the ability to identify occluded trajectories. The second explanation suggests that infants hold two representations of the event, one drawing on general information and the other on specific information, and must combine these into a single, integrated representation. Boys and girls differ in their ability to integrate these two sources of information. Although the current data do not allow us to decide unequivocally between these two explanations, a number of interesting predictions are generated by their consideration. For example, if boys and girls differ in their ability to extract the simple structure of more complex occlusion sequences—and this rests critically on the capacity to represent occluded trajectories—then girls should have more difficulty on tasks that require them to identify the trajectory of objects as the objects move through occlusion, especially if the trajectories are difficult to extrapolate. In addition, this capacity should be related to performance on event-mapping tasks. In contrast, if the important difference between boys and girls is their ability to extract general information about events, then sex differences should be observed on tasks that require infants to represent spatiotemporal and/or categorical information about the objects present in the event. It could be that girls need more time to process the spatiotemporal properties of occlusion sequences or to identify the categories to which the objects belong (e.g., open or closed; inert or self-propelled). Again, differences in performance on these tasks should predict differences in performance on event-mapping tasks.

Regardless of why boys are better than girls at representing and mapping occlusion sequences, the current findings make an interesting prediction. If infants were provided with experiences that helped them identify the simple (or general) structure of an occlusion sequence, they should demonstrate improved event-mapping performance. Wilcox (2007) tested this prediction using a violation-of-expectation task. In this experiment, infants were presented with a variation of the ball–box test event shown in Figure 1A. In the initial phase of the test event, infants saw a box emerge to the left of the screen and return and then a ball emerge to the right of the screen and return (box–ball event). In the final phase, the screen was lowered to reveal a single ball. At 9.5 months neither boys nor girls showed prolonged looking to the final one-ball display. At 10.5 months boys showed prolonged looking, and at 11.5 months boys and girls showed prolonged looking, to the one-ball display. Hence, boys demonstrated successful performance on this task prior to girls. In a subsequent experiment, 10.5-month-old girls were shown pretest trials prior to the test trials that, together, formed an "outline" of the ball–box event. In the first pretest trial, infants saw the box emerge to the left of the screen and return. In the second pretest trial, infants saw the ball emerge to the right of the screen and return. Hence, infants saw the two components of the event—a box that moved to the left of the screen and a ball that moved to the right—one piece at a time. Together, the two components of this outline captured the basic structure of the event. After viewing the event outline, the 10.5-

month-old girls performed like the 10.5-month-old boys: They successfully mapped the box–ball event onto the one-ball display. Other experiments have revealed that it is not simply additional exposure to the objects that facilitates performance but exposure to the trajectory that each object follows as it moves behind the screen. In addition, given sufficient exposure to this event outline, boys and girls as young as 7.5 months can successfully map a box–ball occlusion sequence, although girls need more exposure than boys to the event outline (Wilcox, 2003).

Finally, these results add to a growing number of studies that have reported sex differences in visual processing during infancy (Alexander, Wilcox, & Woods, 2009; Antell & Keating, 1983; Benenson et al., 2004; Creighton, 1984; Kavšek, 2004; Lutchmaya & Baron-Cohen, 2002; Moore & Cocas, 2006; Moore & Johnson, 2008; Quinn & Liben, 2008; Serbin et al., 2001; Servin et al., 1999). The challenge is to identify the factors that contribute to these sex-linked differences in behavior. The differences reported here are consistent with those obtained on other object-processing tasks. For example, there is evidence among humans and monkeys that male infants outperform female infants on tasks requiring them to keep track of specific objects, and their spatiotemporal coordinates, over time (Clark & Goldman-Rakic, 1989; Goldman, Crawford, Stokes, Galkin, & Rosvold, 1974; Overman, Bachevalier, Schuhmann, & McDonough-Ryan, 1997; Overman, Bachevalier, Schuhmann, & Ryan, 1996). Furthermore, these differences have been linked to different rates of cortical maturation induced by the presence of gonadal hormones (Clark & Goldman-Rakic, 1989; Goldman et al., 1974; Hagger & Bachevalier, 1991; Hagger, Bachevalier, & Bercu, 1987). There is also evidence that boys outperform girls on tasks that require the extraction and manipulation of the spatial structure of visual displays (Levine et al., 1999; Linn & Peterson, 1985), particularly when the displays include partially occluded objects (Voyer et al., 1995). Some of the sex differences in the domain of spatial abilities have been suggested to be related to prenatal exposure to androgens (Puts, McDaniel, Jordan, & Breedlove, 2008; Vuoksimaa et al., 2010). What is currently lacking, however, is evidence directly linking hormone levels with sexually dimorphic behaviors (although see Alexander, Wilcox, & Farmer, 2009). Further research along these lines will be important to fully understand early emerging sex differences, such as those observed on event-mapping tasks.

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