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Infants' Ability to Parse Continuous Actions

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In a series of 3 experiments, the authors examined 6- and 8-month-old infants' capacities to detect target actions in a continuous action sequence. In Experiment 1, infants were habituated to 2 different target actions and subsequently were presented with 2 continuous action sequences that either included or did not include the familiar target actions. Infants looked significantly longer at the sequences that were novel. Experiment 2 presented the habituation and test trials in the reverse order. The results showed that infants habituated to the sequence still showed reliable evidence of recognizing the target action during the test trials. Experiment 3 was comparable to Experiment 2, except it tested whether infants could detect a different event segment, namely the transitions between events. The results showed that infants did not discriminate between test trials suggesting that transitions between events are not as easy for infants to recognize.

Keywords: action parsing, infant cognition, event segmentation

Human action is complex—it includes varied contact between actors and objects and flows continuously without clear breaks between individual units. To parse human action at meaningful places is a precocious ability and there have been few investigations of the skill. In a recent article, Zacks and Swallow (2007) highlighted three characteristics of our event segmentation ability derived from experiments on adults. Event segmentation appears to be automatic, the ability scaffolds later memory, and event segmentation is associated with activity in the brain regions including posterior visual and multimodal processing areas. A developmental perspective looking at the origins of this ability could shed new light on the cognitive mechanisms that guide this ability. In this article, we examine some of the precursors to event segmentation, namely parsing continuous human action, and propose a possible bootstrap to this ability.

Developmental studies of the ability to detect structure in continuous human action have focused on infants nearing their first birthday (Baldwin, Baird, Saylor, & Clark, 2001; Saylor, Baldwin, Baird, & LaBounty, 2007). These studies have demonstrated that infants from 9 to11 months segment continuous human action into units that align with actors' goals and intentions. However, infants have been viewing others in action for many months prior to this, so a remaining question concerns younger infants' skills. Several previous studies have demonstrated that infants' ability to make sense of goal-directed action emerges early. However, these previous studies have largely relied on simplified puppet-based motion (e.g., animated head waggling and jumping actions; Sharon & Wynn, 1998; Wynn, 1996), schematic presentations of motion (e.g., with spheres representing agents; Csibra, Gergely, Biro, Koos, & Brockbank, 1999), or presegmented action (Woodward, 1998; Woodward, Sommerville, & Guajardo, 2001). These types of action sequences may be easier for young infants to interpret because they do not require event segmentation and some of the complexity of human action is stripped away. Because much of day-to-day behavior flows continuously, our initial question was whether infants younger than 9 months possess skills for recognizing previously seen segments in continuous human action. This question distinguishes itself from the previous developmental literature by asking whether certain portions of continuous action are more salient than others.

Baldwin and Baird (2001) have highlighted that there are interesting parallels between parsing human actions and language processing. In maturity both processes are unique to humans, they are universal within the human species, and both emerge in a piecemeal fashion starting in early infancy. Building on the parallels between parsing human actions and language processing, we describe a relevant language study. Bortfeld, Morgan, Golinkoff, and Rathbun (2005) found that 6-month-old infants exploit highly familiar words to segment and recognize adjoining words. Infants were familiarized to a novel word that was preceded by a familiar or novel word. At test, infants recognized the word that followed the familiar word but not the word that followed the novel word. These findings suggest that infants are helped by their speech

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partners' tendency to offer a small class of key words repeatedly (thus establishing familiarity) and in multiple different positions (thus establishing unit boundaries). This is not to suggest that this is the only method that infants have to parse the speech stream, but it is one of many possible routes.

In this article, we make an analogy between the Bortfeld et al. (2005) finding and the task of parsing human actions. One possibility is that infants capitalize on knowledge about how objects behave and interact to help them parse continuous actions. Research on infants' physical reasoning has revealed that infants form distinct event categories, such as occlusion, containment, and support (Casasola, Cohen, & Chiarello, 2003; Hespos & Baillargeon, 2001a, 2001b; Hespos & Spelke, 2004; McDonough, Choi, & Mandler, 2003); thus, event categories are established as familiar. Many previous studies on event category boundaries have presented a single event category per condition or subject (Hespos & Baillargeon, 2001a, 2001b, 2006). A few studies have focused on the ability to generalize across event category boundaries by habituating infants to support events and testing generalization to containment events that share or do not share a physical attribute like tightness of fit (Casasola, 2005; Hespos & Piccin, 2008; Hespos & Spelke, 2004). Presegmented or isolated actions may be rare (even in infant-directed action), so it is worthwhile to investigate detection of event categories when they are presented as part of a sequence.

These studies take a first step toward investigating young infants' parsing of continuous actions that more closely approximate those they may see in their every day environments. Although infants in Hespos and Baillargeon's studies (2001a, 2006) can recognize different event categories presented in isolation, it is not clear whether they recruit this skill to recognize familiar events that occur in sequences. Here we tested this possibility directly. Our claim is that one way that infants may learn to parse continuous human action is by observing regularities in how objects behave and interact. They may then use this information to recognize meaningful units in human action sequences.

Experiment 1

The initial step in the investigation was to determine whether and when infants familiarized to a set of actions in isolation recognize the target actions when they are embedded in a continuous sequence. We could then begin to explore more subtle aspects of infants' learning to parse actions. For example, can infants only encode actions seen in isolation first or can they pick out a segment when it has been presented in a continuous stream? Are certain action segments more salient than others?

The rationale for these experiments is similar to research on infants who tested detection and recognition of words (Jusczyk & Aslin, 1995). As a starting point for our investigation, we decided to use single events as target items (*in*, *on*, *over*, and *under*; see Figure 1). These events were chosen because they represent distinct event categories, and previous research has demonstrated that infants have expectations about these event categories as early as 6 months of age (Baillargeon, 2004). Half the infants saw trials that alternated between *in* and *over* events; the other half saw trials that alternated between *on* and *under* events. By habituating half of the infants with two actions and the other half with the other two actions, we could determine the extent to which the habituation to the actions (as opposed to some intrinsic preference for the actions) was responsible for any preferences that infants might display for the sequences. After reaching habituation criterion, infants were presented with test trials that consisted of a ball moving through three events in a continuous back-and-forth trajectory across the stage. Test trials alternated between two kinds: one where two of the three events were familiar or a sequence where all three events were novel. The prediction was that if infants could remember the target actions and detect them in the continuous sequence, they would look longer at the novel compared to the familiar sequences. Finally because previous research on action parsing had only gone as young as 9 months (Saylor et al., 2007), we started with 8-month-olds, and we extended the age group younger to 6 months to capture any potential developmental differences.

Method

Participants

The participants were 38 healthy, full-term infants (18 boys and 20 girls in two age groups): 6 months ($n = 19$; range: 5 months 15 days to 6 months 14 days; $M = 5$ months 28 days) and 8 months ($n = 19$; range: 7 months 12 days to 8 months 19 days; $M = 8$ months 0 days). Half of the infants were assigned to the *in* and *over* condition, and the other half were assigned to the *on* and *under* condition. Seven additional infants were tested but eliminated, 4 because of fussiness, 2 because the observers could not follow the direction of the infant's gaze reliably, and 1 because of inattentiveness.

We obtained infants' names in this and subsequent studies from birth records and from purchasing commercial mailing lists. The participants' parents were contacted by letters and follow-up phone calls. They were given a t-shirt or book as a thank-you gift but were not compensated for their participation. The ethnicity of the sample for this experiment as well as those that follow was 83% non-Hispanic and 17% Hispanic. The racial make-up was 76% White, 5% Asian, 4% Black/African American, and 10% multiracial. The remaining 5% chose not to answer. The education level for the parents of the children who participated were as follows: 1% had some high school, 6% had a high school diploma, 8% had some college, 80% had a college degree or higher, and 5% did not answer.

Apparatus

The apparatus consisted of a wooden display 213 cm high, 106 cm wide, and 78 cm deep. The infants faced an opening that was 77 cm above the floor, 60 cm high, 99 cm wide, and 78 cm deep. Gray marbled contact paper covered the floor of the apparatus, and white cardboard covered the side walls. The back wall was made of cardboard that was orange and had 21 cm of cream-colored fringe covering the bottom portion to allow the experimenter to manipulate the objects on stage. There was a small hole centered in the front of the apparatus 5 cm below the stage floor where a small video camera was positioned to video the infant's face during trials. In the back wall of the stage, centered 41 cm above the apparatus floor, there was a small opening 3 cm high and 13 cm wide used by the experimenter to monitor his or her actions on the

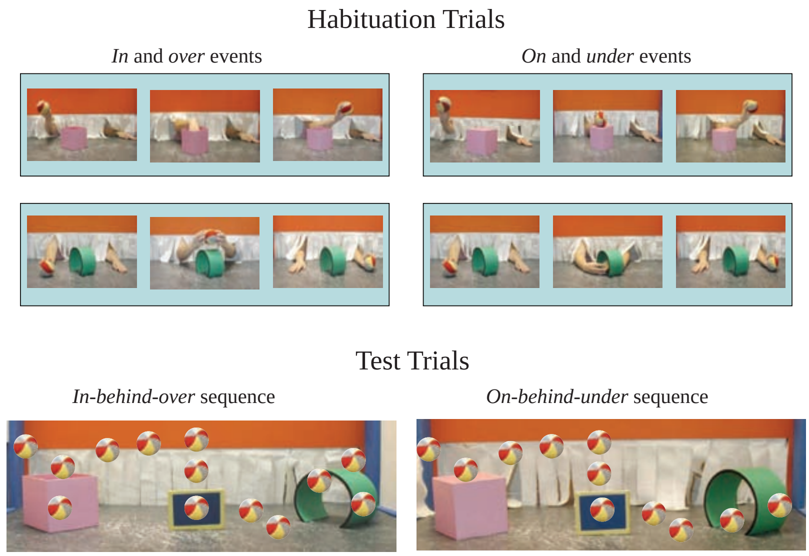

Figure 1. Schematic of the habituation and test trials for Experiment 1. In the habituation and test trials, the experimenter held the ball and moved it continuously through the paths depicted by the various ball positions. Habituation trials were a 3-s cycle repeated continuously until the trial ended. In the test trials, there was a 9-s cycle that was repeated continuously until the trial ended. Infants saw either *in* and *over* events or *on* and *under* events during habituation trials. During test trials, all infants saw an alternation between the two types of test trials.

objects. The opening was cut through the back wall on the sides and bottom only, leaving the top attached to form a flap; this flap served as a visor and prevented eye contact between the infants and experimenter.

The ball used in trials was colorful with six sections of fabric of three different patterns. It also had a bell inside that made a subtle jingle sound as the ball was moved. There were three obstacles that the ball traversed. The box was made out of pink cardboard and was 14.5 cm × 14.5 cm × 14.5 cm and open on the top. The screen was made of blue foam core glued into an *L* shape. The front portion was 10 cm tall and 12 cm wide, and the edges were covered with yellow electric tape. The base was 5 cm deep. The bridge was made out of a piece of plastic pipe 16.5 cm in diameter and 10 cm long. There was a 12-cm portion cut out lengthwise so that the pipe formed a bridge when resting on the cut-out portion. The plastic pipe was covered with green contact paper, and the edges were painted black.

We extended two white curtains from the front corners of the stage to the corners of the room behind the infants to isolate the infants from the experimental room. At the end of each trial, a board covered with red contact paper was lowered in front of the stage.

The video image of the infant's face was viewed by two research assistants in a separate room. The researchers depressed a computer button when the infant attended to the objects on stage and let go when the infant looked away. Looking times and habituation criterion were recorded using XHAB software (Pinto, 1996).

Events

In and over habituation condition. In this condition, infants saw an alternation between two different habituation trials. At the start of the *in* trial, the pink box was in the center of the stage, and the movement consisted of a 3-s cycle where the ball was presented above and to the left of the pink box (from the infant's point of view), then traversed inside the box, and then out above and to the right of the box. At the start of the *over* trial, the bridge was in the center of the stage, and the movement consisted of a 3-s cycle where the ball touched the stage floor on one side of the bridge, then traversed over the bridge and touched the stage floor on the other side of the bridge (see Figure 1). Each cycle was repeated until the computer signaled that the trial ended. Order of the trial presentation was counterbalanced across subjects.

On and under habituation condition. Similar to the previous condition, infants in this condition were presented with two different trials, and trial presentation order was counterbalanced across subjects. In the *on* trial, the orientation of the pink box was inverted so that it formed a pedestal and the ball was tapped on the top of the pedestal instead of inside the box. The *under* trial was identical to the *over* trial with the exception that the ball traversed under instead of over the bridge during the 3-s cycle.

In, behind, over test trials. The test trial consisted of a 9-s cycle that consisted of three 3-s segments in a continuous sequence. When the screen was raised, the box, screen, and bridge were on the stage. At the start of the trial, the experimenter's left hand held the ball above and to the left of the pink box; it entered and exited above and to the right of the box (Seconds 1–3). Next the ball went from centered above the screen to behind, and then it exited to the right of the screen (Seconds 4–6). Finally, the ball tapped the floor in front of the bridge, went over the bridge, and touched down on the other side of the bridge (Seconds 7–9). This cycle was then completed in the reverse order and the entire 18-s cycle was repeated until the computer signaled that the trial ended. The experimenters were trained to make the motion continuous and never pause as they went through the motions. To help the experimenter adhere to the events' scripts, a metronome beat softly once per second.

On, behind, under test trials. This test trial was identical to the test trial above with the exception that the box was inverted to form a pedestal so that the ball was tapped on top and the ball traversed under the bridge.

Procedure

Prior to the experiment, each infant was shown the ball used in the experiment. During the experiment, the infant sat on the parent's lap in front of the apparatus. The parents were asked to refrain from interacting with their infant during the experiment and to close their eyes during the test trials. All trials ended when the infant either looked away for 2 consecutive seconds after having looked at the event for at least 2 s or looked at the event for 60 cumulative seconds without looking away for 2 consecutive seconds. The endings of the trials were determined by a computer, which then signaled the experimenter to lower the screen. The habituation criterion was at least a 50% decline in total looking duration from the first three to the last three habituation trials or a maximum of nine trials. The average number of trials to reach criterion was seven. Infants who did not reach the habituation criterion were eliminated from the data analysis. Each infant viewed six test trials, alternating between in–behind–over or on–behind–under events. The type of test event shown first was counterbalanced across infants. Interobserver agreement averaged 95% per trial per infant for this and the subsequent experiments.

Preliminary analyses revealed no significant effect of habituation condition, gender, or test trial order on the looking times of the infants; the data were therefore collapsed across these variables in subsequent analyses.

Results

Infants looked significantly longer at the novel event sequences compared to the sequences that had familiar events. Figure 2 presents the mean looking times to the habituation trials as well as the novel and familiar test trials. Twenty-nine of the 38 infants had longer looking times for the sequences containing the novel actions ($p = .003$, binomial comparison). Across all participants, the average looking times were 18.1 s for the sequences with the novel actions and 12.3 s for the sequences with familiar actions. A repeated-measures general linear model, with event (novel or familiar) as a within-subject factor and age (6- or 8-month-olds) and habituation condition (in-and-over or on-and-under) as between-subject factors, indicated that this difference in novel and familiar looking times was significant, $F(1, 37) = 20.67$, $p = .001$, $\eta^2 = .36$. The difference between novel and familiar was evident regardless of age group: 6 months only, $F(1, 18) = 13.10$, $p = .002$, $\eta^2 = .42$; 8 months only, $F(1, 18) = 8.2$, $p = .011$, $\eta^2 = .31$. The effect was also evident regardless of habituation condition: habituated to in and over, $F(1, 18) = 10.50$, $p = .005$, $\eta^2 = .37$; habituated to on and under, $F(1, 18) = 10.1$, $p = .005$, $\eta^2 = .36$. This last analysis is consistent with the view that it was the habituation to the actions (as opposed to some intrinsic preference for the actions) that was responsible for the longer looking times at the novel compared to the familiar test trials (see Figure 3).

Discussion

The results are consistent with the view that the infants were able to detect in continuous action the target that they previously saw in isolation. The demonstration that 6- and 8-month-old infants can detect familiar targets in continuous action provides a critical first step in action parsing. Because of the counterbalanced design (e.g., the target actions that were novel for half of the infants were the familiar actions for the other half of the infants), it seems unlikely that the preferences for the novel sequences could be attributed to any low-level perceptual bias. These findings extend the action parsing work done by Baldwin and colleagues to younger infants (Baldwin et al. 2001; Saylor et al. 2007). Although we were surprised that there was no age difference between 6- and 8-month-old infants, the finding demonstrates that the ability to parse events in this way emerges early and could contribute to the development of action parsing by capitalizing on knowledge about objects. Similar to the work by Bortfeld et al. (2005), these findings suggest that infants' ability to parse continuous action may be helped by the repetition of recognized event categories like containment and support events. These repeated event categories establish familiarity and, when viewed in multiple different positions, they establish unit boundaries.

Next we broadened the scope of generalization. Experiment 1 presented isolated actions to encourage infants to detect the sim-

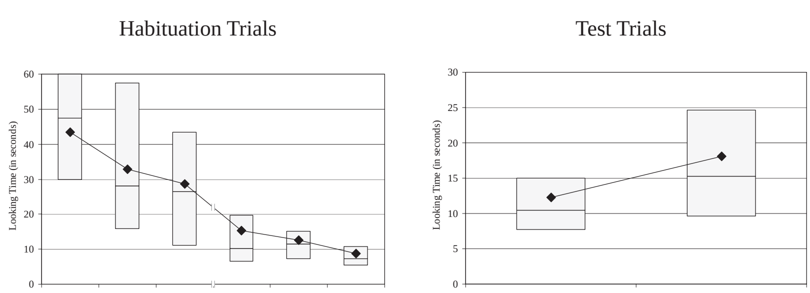

Figure 2. Box plots for mean looking times during habituation and test trials in Experiment 1. In the habituation graph, the boxes represent the means for the first three trials and the last three trials before meeting the habituation criterion. The black diamonds represent the mean, the central line in each box is the median, and the upper and lower portions of the box represent the 75 and 25 quartiles on either side of the mean, respectively. H = habituation.

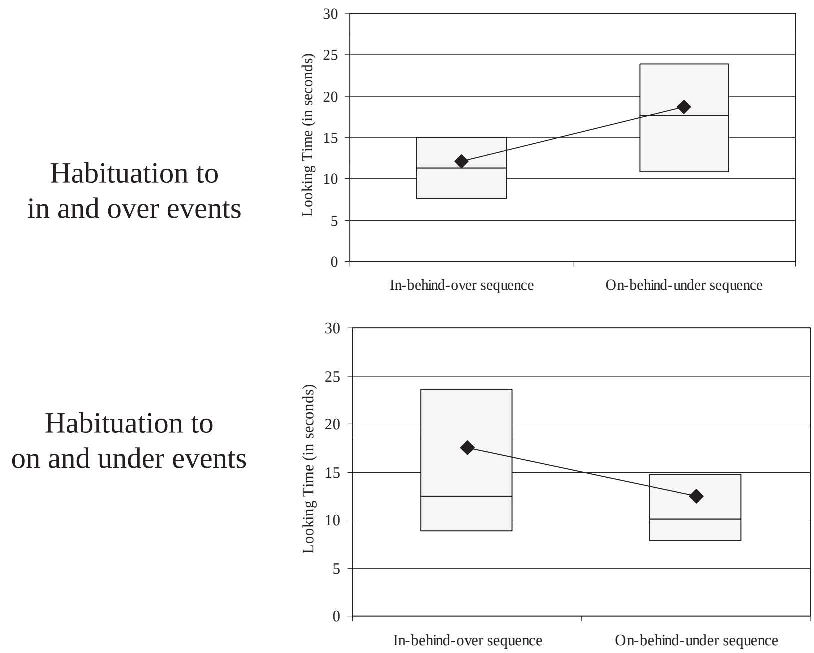

Figure 3. Box plots for the test trials in Experiment 1 separated by habituation condition. The graph demonstrates that infants give opposite patterns to the identical stimuli depending on what they saw during habituation trials. The black diamonds represent the mean, the central line in each box is the median, and the upper and lower portions of the box represent the 75 and 25 quartiles on either side of the mean, respectively.

ilarities in test. These findings reveal that the capacity is present, but actions are rarely produced in isolation in the natural world. Remaining questions include the following: Can infants can pick out a segment when presented with a continuous stream? Are certain action segments more salient than others?

Experiment 2

The question of when infants are able to identify individual actions from their occurrence in a continuous sequence is important for understanding the development of the distinct goals and intentions that underlie individual actions. One means of exploring this issue using the present paradigm is to familiarize infants with continuous action sequences containing the target actions and to see whether they display any tendency to recognize these target actions when they occur in isolation. In other words, we reversed the order in which the infant encountered the actions and sequences (see Figure 4). An indication that infants look significantly longer to the novel isolated actions would imply that they segmented, extracted, and remembered the action when watching the sequence.

Method

Participants

The participants were 38 healthy, full-term infants (19 boys and 19 girls in two age groups): 6 months (n = 18; range: 5 months 22 days to 6 months 12 days; M = 6 months 3 days) and 8 months (n = 20; range: 7 months 16 days to 8 months 13 days; M = 8 months 0 days). Half of the infants were assigned to the in–behind–over condition, and the other half were assigned to the on–behind–under condition. Five additional infants were tested but eliminated, all because of fussiness.

Apparatus and Procedure

The stimuli were identical to Experiment 1. The stimuli used in habituation and test were switched so that infants were habituated to a single long sequence and tested with a novel and a familiar short sequence. The test trials consisted of an alternation between a novel event (one from the condition that they did not see during habituation) and a familiar event (one from the condition that they did see during habituation). For example, after habituation to in–behind–over, test trials consisted of a familiar trial—the ball traversing back and forth in the box presented in alternation with a novel trial—the ball traversing back and forth under the bridge. The combination of novel and familiar test pairings was counterbalanced across participants. The coding and analysis were identical to Experiment 1.

Results

Infants looked significantly longer at the novel compared to familiar event segments. Figure 5 presents the mean looking times to the habituation trials as well as the novel and familiar test trials. Twenty-eight of the 38 infants had longer looking times for the sequences containing the novel actions (p = .008, binomial comparison). Across all participants, the average looking times were 15.4 s for the segments with the novel actions and 10.2 s for the segments with familiar actions. Using the same type of analysis as

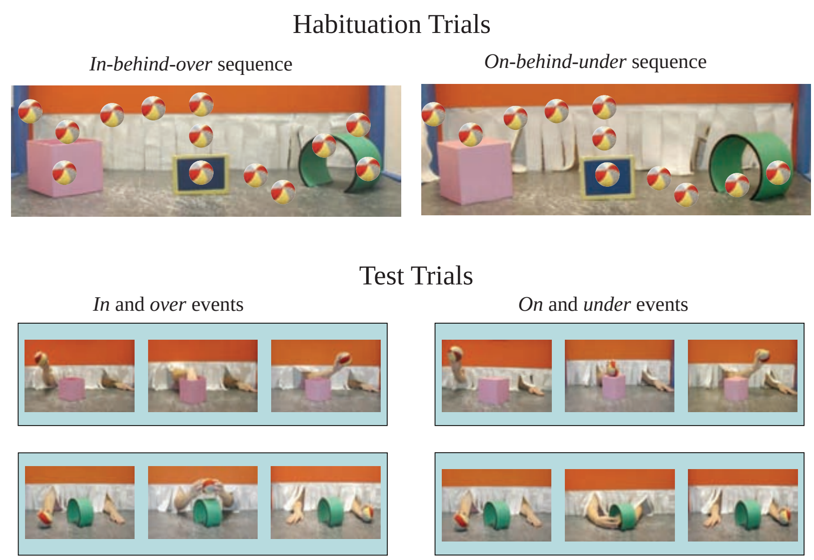

Figure 4. Schematic of the habituation and test trials for Experiment 2. The motion patterns were identical to Experiment 1 except the infants were presented with the long sequence in habituation trials and the target events in test trials. Infants saw either the in–behind–over sequence or the on–behind–under sequence during habituation trials. During test trials, infants saw a novel and familiar test action. The four possible actions are depicted above, but an individual infant only saw trials alternating between two of the four. Test pairs were counterbalanced across participants.

Experiment 1, we found this difference between novel and familiar events was significant, $F(1, 37) = 16.33$, $p < .001$, $\eta^2 = .31$. The difference between novel and familiar was evident regardless of age group: 6 months only, $F(1, 17) = 7.13$, $p = .016$, $\eta^2 = .30$; 8 months only, $F(1, 19) = 11.25$, $p = .003$, $\eta^2 = .37$. The effect was also evident regardless of habituation condition: habituated to in–behind–over, $F(1, 17) = 5.31$, $p = .034$, $\eta^2 = .24$; habituated to on–behind–under, $F(1, 19) = 11.05$, $p = .004$, $\eta^2 = .37$. This last analysis demonstrates that infants had opposite reactions to the same displays depending on what they saw in habituation trials (see Figure 6).

Discussion

The results were consistent with the view that the infants could detect the target action that they previously saw in a sequence. This finding replicated and extended the findings from Experiment 1 providing an even more powerful demonstration that infants have some capacity to recognize actions in a sequence. A critical difference between Experiment 1 and 2 was that Experiment 2 had more distracting features during training so that the generalization may be a better match to real-life learning conditions. Like Experiment 1, there were no age differences in Experiment 2 between 6- and 8-month-old infants.

Taken together, the findings from Experiment 1 and 2 demonstrate four different conditions where infants detected target actions that were presented in isolation or as part of a sequence. Given the variance across experiments and between conditions within each experiment, it is unlikely that four separate low-level perceptual biases could account for these results. A more parsimonious interpretation is that infants use their extensive knowledge about objects to parse human action at units that correspond to event category boundaries. Infants may exploit highly familiar

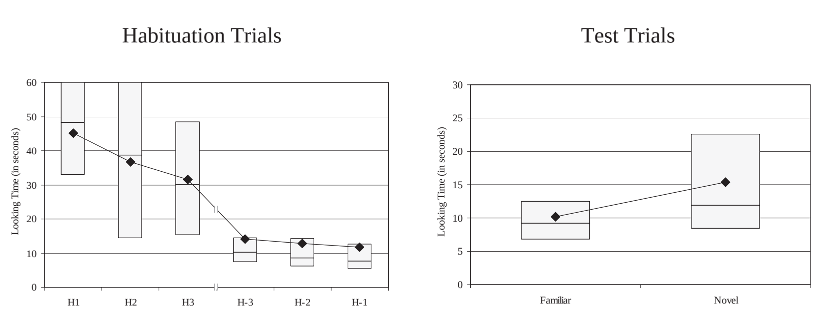

Figure 5. Box plots for mean looking times during habituation and test trials in Experiment 2. The black diamonds represent the mean, the central line in each box is the median, and the upper and lower portions of the box represent the 75 and 25 quartiles on either side of the mean, respectively. H = habituation.

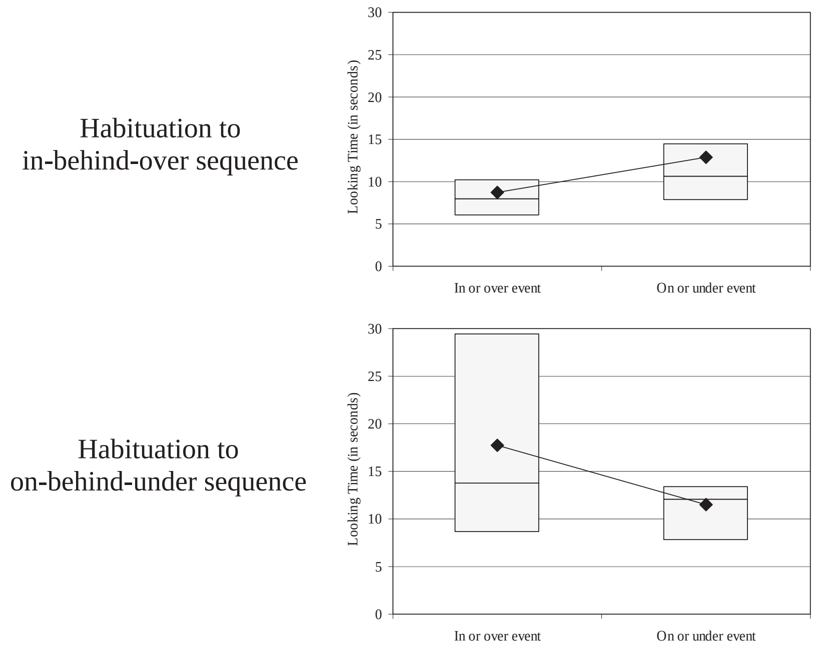

Figure 6. Box plots for the test trials in Experiment 2 separated by habituation condition. Again infants revealed opposite patterns of results depending on what they saw during habituation trials. The black diamonds represent the mean, the central line in each box is the median, and the upper and lower portions of the box represent the 75 and 25 quartiles on either side of the mean, respectively.

event categories to segment and recognize adjoining events. By capitalizing on the small class of event categories to establish familiarity and viewing these events in multiple and different positions, they may establish unit boundaries. One implication of this proposal is that target actions that comprise event categories should have a special status compared to segments of similar duration that do not include events like occlusion, containment, or support.

Experiment 3

Experiment 2 provided evidence that infants were capable of recognizing an action segment that was parsed at event category boundaries. To extend this work, we asked whether events have a privileged status. More specifically, we suggested that event categories are more salient than the transitional units between event categories. To test this hypothesis, we replicated Experiment 2 with the following change: Infants were still habituated to a long sequence, but the test trials consisted of novel and familiar transitions instead of novel and familiar events (see Figure 7).

Method

Participants

The participants were 38 healthy, full-term infants (20 boys and 18 girls in two age groups): 6 months ($n = 24$; range: 5 months 17 days to 6 months 14 days; $M = 6$ months 1 day) and 8 months ($n = 14$; range: 7 months 20 days to 8 months 15 days; $M = 8$ months 2 days). Half of the infants were assigned to the bounce-down condition, and the other half were assigned to the slide-up condition. Four additional infants were tested but eliminated, all because of fussiness.

Apparatus and Procedure

The materials, coding, and analysis were identical to Experiment 2. The procedure was similar to Experiment 2 except for the following changes. We extended the habituation conditions to a 12-s cycle to allow the transitions between events to be 3-s long, and only the on–behind–under sequence was used (see Figure 7). There were four types of transitions (*up* or *down* between the box and the occluder, and *slide* or *bounce* between the occluder to the bridge), and each infant was habituated to a sequence with two of the four transitions. For example, when the ball left the box, it stayed up high until it was above the occluder, and when it came out from the side of the occluder, it performed a 3-s, *J*-shaped slide along the stage floor until is was next to the side of the bridge. Test trials alternated between a familiar transition (one from the condition that they did see in habituation) and a novel transition (one from the condition that they did not see in habituation). The combination of familiar and novel transitions was counterbalanced across participants.

Results

Infants did not show a significant difference between novel and familiar test events. Figure 8 presents the mean looking times to the habituation trials as well as the novel and familiar test trials. Twenty-two of the 38 infants looked longer at the novel segments ($p = .37$, binomial comparison). The average looking times were

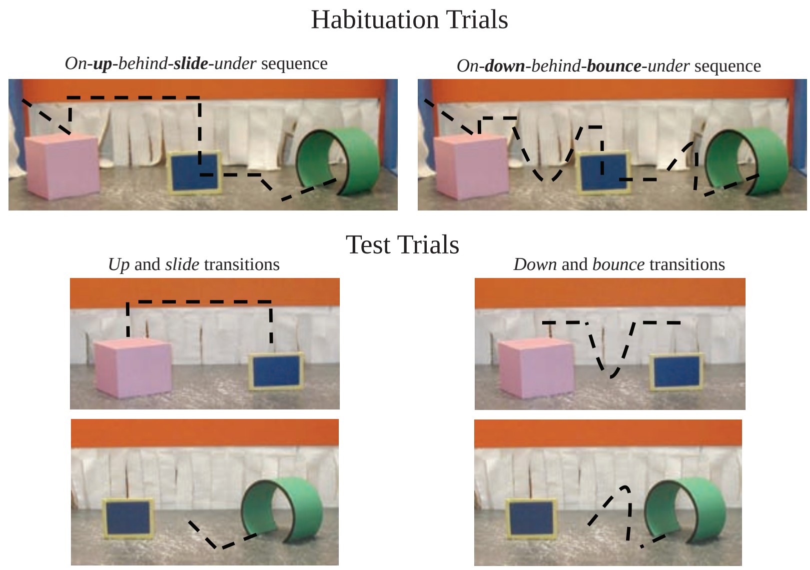

Figure 7. Schematic of the habituation and test trials for Experiment 3. In the habituation and test trials, the experimenter held the ball and moved it continuously through the path depicted by the dotted lines. The habituation trials were a 12-s cycle repeated continuously until the trial ended. In the test trials, there was a 3-s cycle that was repeated continuously until the trial ended. Infants saw either the on–up–behind–slide–under sequence or the on–down–behind–bounce–under sequence during habituation trials. During test trials, infants saw a novel and familiar action. The four possible actions are depicted above, but an individual infant only saw trials alternating between two of the four. Test pairs were counterbalanced across participants.

11.23 s for the novel segments and 9.66 s for the familiar segments. Using the same type of analysis as Experiment 1, we found there was no reliable difference in looking times at novel and familiar test events, $F(1, 37) = 1.57$, $p = .22$, $\eta^2 = .04$. The difference between novel and familiar was not evident in either age group: 6 months only, $F(1, 23) = 1.70$, $p = .21$, $\eta^2 = .07$; 8 months only, $F(1, 13) = 0.18$, $p = .68$, $\eta^2 = .01$. Furthermore, the effect was not evident in either habituation condition: habituated to up-and-slide, $F(1, 17) = 1.75$, $p = .20$, $\eta^2 = .09$; habituated to down-and-bounce, $F(1, 19) = 0.20$, $p = .66$, $\eta^2 = .01$ (see Figure 9).

Next we did an overall general linear model comparing event (novel vs. familiar) as a within-subject factor and experiment (1, 2, or, 3) as a between-subjects factor. There was a significant main effect for event, $F(1, 111) = 32.55$, $p = .001$, $\eta^2 = .23$, a significant main effect for experiment $F(1, 111) = 5.06$, $p = .008$, $\eta^2 = .08$, and a significant Event $\times$ Experiment interaction $F(2, 111) = 3.24$, $p = .043$, $\eta^2 = .06$. Further comparisons demonstrate that Experiment 1 and 2 are different from Experiment 3 (Experiment 1 vs. 3: Event $\times$ Experiment interaction, $F[1, 74] = 5.58$, $p = .02$, $\eta^2 = .07$; Experiment 2 vs. 3: Event $\times$ Experiment interaction, $F[1, 74] = 4.12$, $p = .046$, $\eta^2 = .05$), but Experiment 1 and 2 are not significantly different from each other, $F(1, 74) = 0.10$, $p = .76$, $\eta^2 = .001$. A final analysis looked at the habituation looking times across experiments comparing trials (first three habituation trials to the last three habituation trials) as a within-subject factor and experiment (1, 2, or, 3) as a between-subjects factor. There was a significant main effect of trial (in that looking time decreased over trials, $F[1, 555] = 154.42$, $p = .001$, $\eta^2 = .58$;

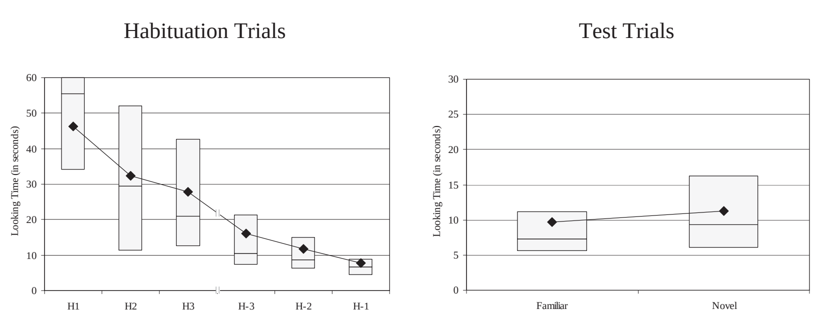

Figure 8. Box plots for mean looking times during habituation and test trials in Experiment 3. There was no predictable pattern to the test trials. The black diamonds represent the mean, the central line in each box is the median, and the upper and lower portions of the box represent the 75 and 25 quartiles on either side of the mean, respectively. H = habituation.

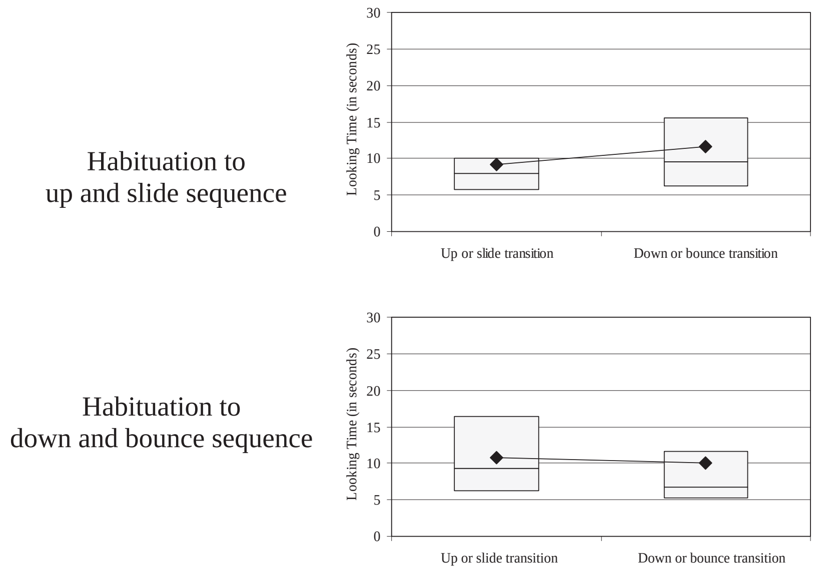

Figure 9. Box plots for the test trials in Experiment 3 separated by habituation condition. The unpredictable pattern occurred regardless of habituation condition. The black diamonds represent the mean, the central line in each box is the median, and the upper and lower portions of the box represent the 75 and 25 quartiles on either side of the mean, respectively.

there was no main effect of experiment or Experiment × Trial interaction ($Fs < 1$).

One could argue that the difference between Experiments 2 and 3 is merely an issue of perceptual scaling. This alternative interpretation suggests that transitions are less different from each other than events, so infants may be less likely to notice differences between transitions. We do not have an objective indication of the sheer perceptual difference across the displays. However to address this alternative interpretation, we compared the looking times on the last habituation trials compared to the first novel and familiar test trials in Experiments 2 and 3. In both experiments, there was a significant increase in looking time to novel trials but not to familiar trials (Experiment 2: novel event, $t[37] = 3.30$, $p = .002$; familiar event, $t[37] = 0.115$, $p = .91$; Experiment 3: novel transition, $t[37] = -2.73$, $p = .01$, familiar transition, $t[37] = -1.23$, $p = .23$). This analysis demonstrates that infants were capable of discriminating between the novel and familiar trials. Since infants could discriminate the difference between novel and familiar transitions, it makes the perceptual scaling interpretation unlikely.

On a related issue, we argue that infants may encode events and transitions differently during habituation trials. If this is true, then recovery scores should be different across Experiments 2 and 3. Recovery scores for the novel and familiar test events were calculated by subtracting the looking time during the final habituation trials from the first novel and familiar test trials. In Experiment 2, the novel and familiar recovery scores were significantly different from each other, $t(37) = 3.80$, $p = .001$. In contrast, in Experiment 3, novel and familiar recovery scores were equivalent, $t(37) = 0.79$, $p = .44$. In addition, for Experiment 3, the looking times during test trials were significantly longer than the looking time to the last habituation trial, $t(75) = 2.59$, $p = .012$, suggesting that both transition displays were novel to the infants. This analysis is consistent with the interpretation that infants encoded the events and transitions differently.

Discussion

Infants in this experiment failed to discriminate between the novel and familiar transitions. The infants' behavior was unpredictable regardless of age group or habituation condition. The infants' performance in Experiment 3 was significantly different from performance in Experiments 1 and 2. One alternative interpretation of the findings from Experiment 1 and 2 is that infants merely noticed the displays that included novel motions. However, the findings from Experiment 3 mitigate this interpretation. In Experiment 1 and 2, we tested infants' ability to discriminate novel and familiar events, and in Experiment 3, we tested infants' ability to discriminate novel and familiar transitions. The critical difference was that infants successfully detected novel from familiar events but did not detect novel from familiar transitions. If performance in these experiments was guided by an ability to detect novel motions alone, then the results of Experiment 3 should have been similar to the first two experiments. In particular, the recovery scores between Experiments 2 and 3 should have been similar, and they were not. In Experiment 2, infants saw a sequential display during habituation trials, and when they were presented with a novel target event during test trials, they recaptured attention and generalized habituation to the familiar target event. In contrast, for Experiment 3, infants saw a sequential display during habituation trials and dishabituated to both novel and familiar transitions in test trials. These findings are consistent with the view that not all 3-s segments of action are remembered equally. We speculate that event categories are a privileged class that could aid infants in creating boundaries to parse continuous human action.

General Discussion

The experiments demonstrated that infants can detect certain segments in continuous human action. In particular, exposure to a repeated isolated action leads infants to look longer at action sequences that do not contain the habituated action (Experiment 1). Habituating infants to isolated actions is not a necessary condition for later detection of the actions in a sequence. Infants who saw the target action first embedded in a sequence later looked longer at novel actions that were not in the initial sequence (Experiment 2). Finally, not all portions of a sequence are recognized with equal facility. Infants failed to discriminate between novel and familiar transitions (Experiment 3). Whether infants may be able to detect the target transitions under different circumstances remains to be seen. For instance, if we habituated infants to an isolated transition event, it is possible they may recognize it when tested in a long sequence.

The full extent of young infants' ability to detect specific actions in continuous human motion has yet to be determined. Previous research indicates that infants by 10–11 months can interpret action sequences when they are not familiar with the particular events or people (as in Baldwin et al., 2001) or when the events are novel (as in Saylor et al., 2007). Together these findings suggest that infants' parsing abilities transcended the need for detailed knowledge of the people or objects involved. The present results extend these findings to younger infants and provide the first demonstration that not all segments of a sequence are equal. Infants as young as 6 months can recognize actions in a continuous action sequence and discriminate novel from familiar events but do not discriminate novel from familiar transitions.

One remaining question concerns why infants were more successful at detecting novel events than novel transitions. Our argument is that infants were more familiar with event categories (e.g., support, containment, covers, occluders) than transitions. On this account, event categories may be privileged for young infants, and this privileged status may enable infants to detect such events in continuous human action before they are able to interpret what is happening during transitions. This account hinges on the idea that conceptual knowledge is guiding behavior in this task. It is possible that later in development or under different experimental paradigms that transitions become salient. For example, research on 10- to 11-month-old infants suggests that transitions offer a rich source of information about subsequent goals (e.g., Baldwin & Baird, 2001; Saylor & Baldwin, 2004). Our data do not resolve this debate, but it is a worthy goal for future investigations.

It remains to be seen whether infants can parse at more than one level of description. A complete theory of event parsing will probably have influences from multiple sources. Studies addressing how parsing events occur have come from linguistics (Talmy, 2003), development (Baldwin et al., 2001; Mandler, 2006), and computational modeling (Marr, 1982). For example, an event as mundane as going out for lunch could be parsed at the high-level goal of gaining nourishment or a more detailed level of description involving leaving the office, walking to a restaurant, ordering, and eating. Shipley and Maguire (2009) described a microlevel of description called the *curvature extrema* unit analysis that borrows from the object perception literature involving parsing objects from the perceptual array. Regardless of the specific level of description, there are likely to be physical and temporal regularities that happen to be correlated with the event categories and could have generated infants' parsing skill. The correlations are probably not perfect, but the failures could indicate predictions about developmental differences and ambiguous parsing situations. The work presented here is not to suggest that knowledge of event categories is the only method that infants have to parse continuous human action, but it is one of many possible routes.

In conclusion, these findings support our proposal that early event segmentation may capitalize on what infants know about how objects behave and interact. We suggest that infants use their physical knowledge to help them parse continuous human action at event boundaries because repeated event categories establish familiarity, and when viewed in multiple different positions, they establish unit boundaries.

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