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Action Interrupted: Processing of Movement and Breakpoints in Toddlers and Adults

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Abstract

From early in development, segmenting events unfolding in the world in meaningful ways renders input more manageable and facilitates interpretation and prediction. Yet, little is known about how children process action structure in events comprised of multiple coarse-grained actions. More importantly, little is known about the time-course of action processing in young children or about the specific features that recruit attention. This is particularly true when we consider action that pauses unexpectedly—as actions sometimes do—violating the expectation of a continuous unfolding of motion. We assessed visual preference to intact and disrupted actions embedded within a multi-action event in toddlers and adults. In one condition, pauses were inserted at intact action boundaries whereas in the other condition they disrupted action. Attention in both groups was recruited to the disrupted relative to intact events. Time-course analyses, however, revealed developmental differences in sensitivity to the movement features (e.g., motion, pauses, and transitions) of disrupted events.

Introduction

From early in development, young children make sense of the actions and events that unfold in their world (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Stapel, Hunnius, van Elk, & Bekkering, 2010; Hunnius & Bekkering, 2010; Stapel, Hunnius, & Bekkering, 2012). Indeed, within the first year there is evidence that infants use information within continuous actions to segment those actions into meaningful units (Baldwin, Baird, Saylor, & Clark, 2001). For example, infants parse continuous action into subcomponents (Hespos, Saylor, & Grossman, 2009), recognize disruptions of biological motion (Marshall & Shipley, 2009), encode the outcomes of specific actions (Perone, Madole, & Oakes, 2011), and discriminate complete from incomplete goal-directed activity (Reid, Csibra, Belsky, & Johnson, 2007). In large part, what we know about infant action processing is based on responses to discrete, familiar coarse-grained actions. Little is known about how children process action structure in events that are comprised of sequences of coarse-grained actions. Further, little is known about the time-course of action processing in infants and young children or about the specific features of action that recruit attention. This is particularly true when we consider action that pauses unexpectedly—as actions often do—violating the expectation of a continuous unfolding of motion. Most of the time, action unfolds about us smoothly and predictably. Mother strides fluidly into the kitchen, opens the refrigerator, and returns with the milk. The toddler, having mastered his first steps, moves relatively predictably toward

many exciting new goals. Children on the playground alternate, moving fluidly up and down on the teeter-totter. Yet often actions are less fluid such as when we forget what we meant to do, make an error, or set out to surprise someone. Consider, for example, the mother who strides headlong into the kitchen only to pause mid-stride to remember what she intended to fetch, the toddler who pauses awkwardly before falling higgledy-piggledy on his bum, or the child on the teeter-totter who surprises his playmate by pausing him in midair! Of interest is whether toddlers are sensitive to temporal disruptions in events comprised of multiple actions and how attention is allocated to process such disruptions.

Several sources of information – from bottom-up perceptual features to top-down conceptual knowledge of event structure – potentially inform interpretations of actions and events. In adults, these sources of information likely operate in tandem (Zacks & Tversky, 2001). The present research investigated sensitivity to disruptions of events comprised of 3 coarse-grained actions in 24-month-olds and adults using a preferential looking paradigm. Using time-course analyses of looking behavior, we explored the allocation of visual attention at macroscopic and microscopic temporal scales to evaluate the role of two potential sources of information: movement features (i.e., motion) and action boundaries (i.e., breakpoints).

At a global level, the events in our world are continuous (mom pausing in the kitchen and the toddler tumbling unsteadily become part of a continuous flow of information in a larger event), but our psychological experiences of these events in real time are discrete. Event segmentation is the process by which individuals break up continuous activity into discrete, potentially meaningful units of experience. A quarter century of research has shown that observed human activities are structured hierarchically in cognition into action parts and subparts (Bower, Black & Turner, 1979; Zacks & Tversky, 2001; Shipley & Zacks, 2008). Segmenting the temporal stream into meaningful units of action renders complex input more manageable and facilitates interpretation and prediction (Grafton & Hamilton, 2007; Tversky, Zacks, & Hard, 2008; Wilson, Papafragou, Burger, & Trueswell, 2011).

This hierarchical organization has been termed partonomic (Tversky & Hemenway, 1984): based on salient components rather than featural similarity. Events are typically partitioned into coarse-grained units initially (Bower et al., 1979) with each coarse-grained unit comprised of fine-grained subcomponents. There is strong agreement among adults in the segmentation of events into action units and boundaries (breakpoints; Newtonson, 1973; Newtonson & Enquist, 1976; Speer, Swallow, & Zacks, 2003) and neuroimaging research reveals increases in transient brain activity at locations within events identified as meaningful parts and subparts (Speer, Zacks, & Reynolds, 2007; Zacks, Braver, et al., 2001; Zacks & Tversky, 2001).

Adults detect action units, in part, by processing changes in speed and acceleration (Stadler, Springer, Parkinson, & Prinz, 2012; Stapel et al., 2012; Zacks, 2004; Zacks, Kumar, Abrams, & Mehta, 2009) and integrating this information with conceptual knowledge about intentional event structure (e.g., goals; Hard, Recchia, & Tversky, 2011). A growing body of research suggests that infants and toddlers are similarly sensitive to features of dynamic human action such as velocity (e.g., speed; Rosander, Nyström, Gredebäck, & von Hofsten, 2007) and trajectory (e.g., path and manner; Pruden, Göksun, Roseberry, Hirsh-Pasek, &

Golinkoff, 2012; Pulverman, Golinkoff, Hirsh-Pasek, & Buresh, 2008), but are also capable of recognizing salient boundaries within the structure of the event (Baldwin et al., 2001; Hespos et al., 2009).

The developmental origins of this ability emerge within the first year of life (Baldwin, et al., 2001; Hespos, Grossman, & Saylor, 2010; Saylor, Baldwin, Baird, & LaBounty, 2007; Reid, Csibra, Belsky & Johnson, 2007). One salient visual feature in infancy is motion (Abrams & Christ, 2003; Bidet-Ildei, Kitromilides, Orliaguet, Pavlova, & Gentaz, 2013; Kremenitzer, Vaughan, & Dowling, 1979; Rosander et al., 2007). Between 6 and 14 weeks of age infant's ability to discriminate motion direction (Atkinson, 2000; Braddick, Birtles, Wattam-Bell, & Atkinson, 2005) and to smoothly pursue moving objects (Rosander & von Hofsten, 2002) improves rapidly. Infants isolate and individuate action units from continuous events (Hespos et al., 2009; Wynn, 1996), are sensitive to features of biological motion (Reid, Hoehl, & Striano, 2006), discriminate patterns of motion for everyday events (e.g., brushing hair vs. brushing teeth; Bahrick, Gogate, & Ruiz, 2002), and track changes in action trajectory (i.e., path; Pruden et al., 2012; Pulverman et al., 2008), form (i.e., manner; Pruden et al., 2012; Pulverman et al., 2008), and outcome (Olofson & Baldwin, 2011; Sootsman Buresh & Woodward, 2007). Taken together, this research provides a strong case for the role of motion features in the perception of events early in development.

Research in adults however, suggests that breakpoints (i.e., temporal junctures that separate units of action) may also be essential to event segmentation. Adults increase attention to these breakpoints particularly when they segment actions at a coarse level (Baldwin, DeCamp, Hard, Baldwin, and Roy, 2011) and are sensitive to temporal junctures that designate both coarse- and fine-grained action components (Hard et al., 2011; Zacks et al., 2009). Importantly attention to breakpoints is not independent of motion features such as speed and acceleration. Breakpoints, in conjunction with motion cues, may assist adults in bridging perceptual and conceptual information (e.g., goals) for action interpretation (Loucks & Baldwin, 2009). Event Segmentation Theory emphasizes the importance of both dynamic features and breakpoints (EST; Zacks, Speer, Swallow, Braver, & Reynolds, 2007). EST holds that event boundaries are detected by virtue of processing unpredicted feature changes and posits that observers must process event structure to generate predictions about what will happen next. Such predictions allow for adaptive proactive responses and are a key feature of models of control in psychology (Neisser, 1967) and neuroscience (Schultz & Dickinson, 2000).

Do young children, like adults, make use of information conveyed at breakpoints to process motion events? Infants and toddlers are sensitive to disruptions in continuous action (Friend & Pace, 2011; Saylor et al., 2007), yet the way in which they divide the flow of information remains unclear. In the only study, to our knowledge, to investigate the relative influence of event components on looking patterns prior to age 2, Hespos et al., (2010) habituated infants to events consisting of actions (e.g., occlusion – a ball goes behind an occluder; containment – a ball goes in a container) and a transition between actions (e.g., bounce, slide). Test events consisted of either a novel action and familiar transition or familiar action and novel transition. The novelty of the actions predicted performance: infants looked significantly longer at novel action/familiar transition compared to familiar action/novel transition

segments suggesting that motion is more salient than transitions between actions. Similarly, Friend and Pace (2011) showed that most 24-month-olds could segment a 3-action event sequence to individuate a single, coarse-grained, action. However, even as late as 24 months of age, a substantial minority of toddlers (20%) did not show evidence of event segmentation. These findings leave the age at which children utilize breakpoints to segment events indeterminate. Thus, little is known about how action boundaries guide attention in young children. Of interest is the extent to which toddlers attend to motion dynamics and breakpoints in event processing to make sense of actions that violate the expected temporal structure of motion.

Most extant research on the development of event processing has investigated sensitivity to the structure of single, highly familiar, coarse-grained actions (e.g., placing a pastry in the mouth, or picking up a towel from the floor; Baldwin, 2001; Reid, 2009) in infants and less is known about sensitivity to events comprised of multiple coarse-grained actions in sequence or about the development of event processing post-infancy (but see Pace, Carver, & Friend, 2013, for recent neurophysiological evidence). Further, extant research relies upon macro-level, dichotomous measures of visual attention (Baldwin et al., 2001; Hespos et al., 2010; Hespos et al., 2009) that cannot reveal the event features that recruit attention. A micro-level analysis of events comprised of multiple, coarse-grained actions is required to reveal developmental patterns in attention to motion features and breakpoints.

In the present research, expected motion was violated in a sequence of coarse-grained actions. We began with a standard preferential looking procedure to determine whether disruptions in events comprised of sequences of coarse-grained actions recruit attention in adults and toddlers in the same way as simple coarse-grained events do in infants. Macro- and micro-level data are reported to explore how attention to event features changes with development.

We explored the processing of violation of expected motion in toddlers for three reasons. First, although sensitivity to motion features has been demonstrated in infants, recent research suggests that infants attend preferentially to motion features over breakpoints and little is known about when sensitivity to breakpoints emerges (Baldwin, et al., 2011; Hespos et al., 2010). Second, although toddlers spontaneously segment events in the laboratory, a substantial minority does not succeed suggesting that event segmentation skills undergo development in the toddler period (Friend & Pace, 2011). Finally, whereas infants and toddlers are quite adept at processing spatial events (Pulverman, Song, Hirsh-Pasek, Pruden, & Golinkoff, 2013; Pruden, Hirsh-Pasek, & Golinkoff, 2008), understanding of spatial concepts develops well into the preschool period (Gentner, 1982; Gentner, Özyürek, Gürcanli, & Goldin-Meadow, 2013). Thus toddlerhood represents a period of development intermediate to the early sensitivity to motion cues in infancy and the understanding of motion events that is increasingly consolidated in spatial language in the preschool period.

We expected, consistent with previous research (Baldwin et al., 2001; Friend & Pace, 2011), that both toddlers and adults would detect temporal disruptions and that attention would be recruited by the disrupted event. To assess the allocation of attention within events, epochs of coarse-grained action and breakpoints were identified, and visual attention was measured,

frame-by-frame, over the course of the event. We anticipated that both adults and toddlers would allocate attention preferentially to breakpoints that violated natural action boundaries since these would be highly salient. Thus our hypotheses extend across macroscopic and microscopic time scales. We investigate the time-course of visual attention with specific emphasis on the features to which children and adults attend when action is disrupted unexpectedly.

Participants observed an event sequence comprised of three coarse-grained actions in which pauses were inserted at intact action boundaries (i.e., at action completion) or mid-action following Baldwin and colleagues (2001) and Pace, Carver, & Friend (2013). Intact and disrupted events were presented simultaneously and looking behavior was measured to assess visual preference. If toddlers are sensitive to event disruptions, then visual attention should be preferentially allocated to junctures that violate expectations of the natural flow of perceptual information. This approach allows us to address the classic work showing that children are sensitive to temporal disruption early in life by providing evidence on how that disruption is processed. In doing so, we provide broader evidence regarding the perceptual features to which adults and children attend to process motion meaningfully.

Method

Participants

Toddler Sample—Twenty-nine toddlers (14 girls and 15 boys) between 21- and 28-months of age ($M = 24;21$, range = 21;3 to 28;6) participated in the final sample. An additional 6 toddlers were excluded due to equipment malfunction ($N = 1$), fussiness ($N = 3$), or because they failed to attend to the familiarization videos for at least 50% of the total duration during the familiarization phase ($N = 2$).

Adult Sample—Twenty-eight adult undergraduates (24 women and 4 men) received course credit for their participation (M age = 21.7 years; range = 18.6 to 31.8). These numbers reflect the gender distribution of our participant pool. Five additional adults were tested, but excluded due to equipment malfunction ($N = 2$) or because they fixated on a single computer monitor for the entire duration of the video in one or more blocks ($N = 3$).

Materials

All participants observed videos of a female agent performing a relatively novel event comprised of three sensible actions. The actions were constructed into an activity station to facilitate a single fluid event. Whereas each action was a sensible everyday action, the novelty of the event resides in the configuration of these actions. This enabled us to ask how attention is allocated to motion and breakpoints over the course of a sequence of actions. The activity station was organized so that each action led logically and proximally to the next action. This is important because, in most natural action sequences, the transitions between major segments are smooth. That is, breakpoints are places where simultaneously one segment ends as another begins. More importantly, each action conditions the subsequent action. In the present case for example, a truck moved along the track until it stopped below a pulley. This initiated a transition between actions conditioning the

subsequent action, hoisting the clown with the pulley that brought it to the top of the ramp. This initiated the transition to a third action: pushing the clown down the ramp in a car.

Three versions of the event were created, each with a different starting action. We chose only those event sequences that met the criteria above: smooth transitions between actions, with each action leading logically and proximally to the next such that every action was predicated on the action immediately preceding it. Sequence 1 began with the agent placing the clown in the truck and pushing a button so that it moved along the track (Track), continued on to the Pulley, and completed with the Ramp (i.e., Track-Pulley-Ramp). Sequence 2 began with the Pulley, continued on to the Ramp, and completed with the Track (Pulley-Ramp-Track). Sequence 3 began with the Ramp, continued on the Track, and completed with the Pulley (Ramp-Track-Pulley). All participants observed three blocks of trials; each block consisted of one of the three event sequences, each with different starting action. Participants were randomly assigned to order of sequence presentation. In the final toddler sample, 10 participants observed sequence 1 first (in block 1), 10 observed sequence 2 in block 1, and 9 observed sequence 3 in block 1. The duration of each event (sequence 1, 2, and 3) was 16 s. In the final adult sample, 10 participants observed sequence 1 first (in block 1), 9 observed sequence 2 in block 1, and 9 observed sequence 3 in block 1.

2.1.3 Apparatus and Procedure—A preferential-looking procedure was used to determine whether visual attention was recruited to intact versus disrupted events and how attention was allocated across motion and coarse-grained action boundaries. Toddlers were seated on their caregiver's lap approximately 43-inches away from two Acer LCD P221W (1680 × 1050) 22-inch video monitors. Both monitors were situated on a 48" × 48" table in a dark curtained enclosure. The distance between the two monitors was 29-inches, center-to-center. A small red light was placed between the two monitors to center participants' attention at the onset of each block. A video camera positioned above the light was connected to a third computer monitor in an adjacent room to provide live video of the participant's behavior during the study and to record visual fixations to each monitor using iMovie.

From the adjacent room, an experimenter observed participants on the monitor and administered the study from a computer with Habit 2000 software (Cohen, Atkinson & Chaput, 2004). Visual fixations to the two monitors during the study were coded online by the experimenter who pressed a button to indicate when the participant was looking to the left or right screen and released the button when the participant looked away or shifted their gaze. During the online coding, the experimenter could not see the stimuli on the screens and the coding computer did not display phase information (e.g., pretest, familiarization, test) during the study. Due to the requirement for coding to millisecond accuracy, visual fixations were also coded offline by a primary and a reliability coder using SuperCoder 2008 software (Hollich, 2008). All analyses were conducted with SuperCoder data.

The study consisted of three within-subjects blocks. Order of video sequence (1–2–3) and initial side of presentation (Left / Right) were counterbalanced across participants by block. All participants saw all video sequences and saw the disrupted video sequence presented on the right and on the left. The only between-subjects factor was which sequence appeared

first and on which screen initially. The starting position of the video (Track, Pulley, or Ramp) was counterbalanced within participants across blocks; participants were randomly assigned to one of the three starting positions per block. Each block consisted of two fixed-length phases: familiarization and test. During familiarization, participants observed identical videos of the original video event presented simultaneously on both screens. Familiarization events were 11.5 seconds in duration including .75 sec prior to the onset of action 1 and following the offset of action 3. The video began and ended with the actor in a state of rest looking out toward the participant. The video was looped 3 times. An inter-stimulus interval (ISI) of 2.5 seconds separated repetitions of the event during which participants observed a black screen and were reoriented to the center with a blinking red light operated by the experimenter. Thus, the entire familiarization phase was approximately 40 seconds.

The familiarization phase served two purposes. First, it insured that all participants had minimal exposure to the event so that we could evaluate the influence of changes in event structure on attention allocation. Since preferential looking is very sensitive to novelty, providing this minimal exposure insured that attention allocation would not be confounded with novelty. Second, it provided a baseline measure of side bias. To be included, participants were required to attend to the familiarization videos for at least 50% of the total duration. Two participants in the toddler sample did not meet this criterion and were not included in the analyses.

After familiarization, participants observed test videos (Intact and Disrupted) presented simultaneously on both monitors. The test videos were 16 seconds in duration, including .75 sec prior to the onset of action 1 and following the offset of action 3 as in the familiarization videos. The action sequences were 14.5 sec in duration from the onset of action 1 to the offset of action 3. Test videos were identical except for the specific location of pauses inserted into each action. In the Intact video, a 1.5-second still-frame pause was inserted at the end of each action (1, 2, 3) coincident with the naturally occurring boundary. In the Disrupted event sequence, a 1.5-second still-frame pause bifurcated each action (see Figure 1). Test videos were looped three times, for a total duration of 55.5 seconds including ISI. Thus, the total duration of each block including familiarization and test phases was approximately 1.5 minutes. Videos were synchronized to begin and complete at the same time. Of interest was how participants would allocate attention to disrupted versus intact events.

Results

Two independent coders were randomly assigned to code participant fixations offline using the SuperCoder 2008 program (Hollich, 2008). Both coders, blind with respect to experimental manipulations, classified visual fixations (onset and offset) to the two monitors on a frame-by-frame basis. To establish inter-rater reliability, each coder performed secondary offline coding for 20% of the videos for which they served as the primary coder. Inter-rater reliability was above 95% ($r = .96$) between coders across samples.

Macro-level Looking Time Analyses

To determine whether toddlers demonstrated baseline looking biases, we compared their proportion looking time to left versus right screens during familiarization phases. A paired samples t-test conducted for proportion of looking during familiarization to the left ($M = .46$; $SD = .19$) and right ($M = .51$; $SD = .20$) screens revealed no significant differences, $t(25) = -.634$, $p = .532$, $d = .12$. Similarly, a t-test conducted on adult looking times revealed no significant differences in looking to left ($M = .55$; $SD = .23$) or right ($M = .44$; $SD = .24$) screens during familiarization, $t(27) = 1.165$, $p = .254$, $d = .22$. This indicates that there was no systematic side preference in either our toddler or our adult participant group.

It is important to note that, during the test phase, the pause in the disrupting condition preceded the pause in the intact condition by .61 sec (on average). To test for the possibility that attention was diverted to the disrupted videos by this breakpoint, we calculated a paired-samples t-test on the frequency of looks across conditions. There was no significant difference in look frequency indicating that the two conditions recruited looks equally ($p = .121$). Thus, differences in look duration between conditions can be attributed to attention maintained by specific features of the motion event such as the timing of pauses and breakpoints relative to the actions comprising the event.

To examine sensitivity to event disruptions, we compared visual attention to the intact and disrupted videos using proportion looking time to intact versus disrupted events as the dependent measure. Proportion looking to the intact event was calculated by dividing time spent looking toward the intact event by total looking duration in each block (the sum of the time each participant spent looking at either screen). Likewise, proportion looking to the disrupted event was calculated by dividing time spent looking toward the disrupted event by total looking duration in each block. A repeated measures ANOVA was conducted with Block (1, 2, 3), Video Sequence (1, 2, 3), and Condition (Intact, Disrupted) as within-subjects factors and with Group (toddlers, adults) as the between-subjects factor. The analysis yielded only a significant effect of Group ($F(1,53) = 172.13$, $p < .001$, partial $\eta^2 = .76$, $power = 1$) indicating that toddlers spent more time looking overall ($M = 31.82s$) than did adults ($M = 14.27s$) but, importantly, no effects of block ($p = .867$) or video sequence ($p = .317$). We proceed with the primary analyses collapsing across counterbalancing orders and video sequence.

A Repeated Measures ANOVA using baseline-corrected proportion looking to each Condition (Intact, Disrupted) with Group as a between-subjects factor revealed a main effect of Condition, ($F(1, 55) = 23.35$, $p < .001$, partial $\eta^2 = .30$, $power = .99$) and no effect of Group. Both groups looked longer at disrupted ($M = .54$; $SD = .12$) relative to intact events ($M = .42$; $SD = .12$). Because the ages of our toddlers spanned about 7 months, we conducted a median split at 25.7 months and repeated this analysis across younger and older toddlers to ascertain whether age differences within our sample might have influenced our findings. There was no significant difference between younger and older toddlers in looking time across Conditions ($p = .132$). Our results are consistent with previous findings showing that young children are sensitive to disruptions of individual, coarse-grained actions (Baldwin et al., 2001) and support the hypothesis that this extends to events comprised of

multiple coarse-grained actions (Pace, Carver, & Friend, 2013). Of interest then, are the features of disrupted events that recruit and maintain attention.

Micro-level Looking Time Analyses

To investigate looking behavior at a fine-grained temporal scale, we identified epochs of interest defined by periods of movement, pauses, and transitions between actions within the intact and disrupted events. Eight epochs were identified for each condition (see Table 1). For example, Epoch 1 for disrupted events was defined by the period of motion from the onset of the first action to the inserted pause and the offset of the pause to the completion of the first action whereas Epoch 1 for intact events was defined by the period of motion from the onset to the offset of the first action. Thus, Epoch 1 reflects the total period of motion in the first action across conditions. In the disrupted event, this period of motion is bifurcated by a pause whereas in the intact event, it is continuous. Epoch 2 was defined as the pause that interrupted the first action for the disrupted event and as the pause that coincided with the natural action boundary for the intact event. Epoch 3 was defined by the transition from the first to the second, and second to third, action in both conditions (see Figure 2 for an illustration of the definition of epochs across actions and conditions; this procedure was followed for each event sequence).

The absolute duration for epochs across conditions was equivalent, but the relative duration of epochs differed across actions. Once the epochs were identified, proportion looking within each epoch was calculated as a function of absolute epoch duration. In this way, looking times were normalized across epochs.

Because our omnibus test revealed no effects of Action or Sequence on looking times, to explore the salience of specific motion features in each condition, we collapsed epochs across Action (1, 2, and 3) to create three epochs of interest per condition: Motion, Pauses, and Transitions. We conducted a Condition X Epoch repeated measures ANOVA with look duration as the repeated measure and Group as the between-subjects factor. The analysis yielded a Condition X Epoch X Group interaction ($F(1, 53) = 3.975, p = .025, \text{partial } \eta^2 = .13, \text{power} = .69$). When this analysis was repeated with younger and older toddlers as the two age groups, there were no significant effects. Of particular importance to the present analyses, there was no interaction of age group with Condition and Epoch ($p = .759$) indicating that younger and older toddlers allocated attention similarly across Epochs within the Intact and Disrupted videos.

Planned comparisons of looking patterns by Condition and Group revealed that looking during pauses was significantly greater than looking during transitions for toddlers in the Disrupted Condition, $t(28) = 2.62, p = .014, d = .49$, indicating that, as expected, attention was recruited to a greater extent by pauses that disrupted ongoing motion than by pauses that occurred at natural action boundaries. Interestingly, look duration during epochs of motion was also significantly greater than looking during transitions, $t(28) = 2.72, p = .011, d = .50$, with epochs of motion and disrupting pauses recruiting statistically equivalent visual attention. These effects did not obtain in the Intact Condition; rather toddlers allocated their attention evenly across the epochs of interest ($p = .796$; see Figure 3). Visual inspection of

the data revealed no outliers in the toddler sample on either the macro- or micro-level measures.

The finding that toddlers discriminate intact from disrupted events is consistent with the developmental literature and with previous findings in adults. These data provide the first evidence that the mechanism underlying this effect is attention to both the motion and the temporal disruption itself. Thus, temporal disruptions do not increase the salience of the event as a whole. Rather, the disruption itself is salient and recruits attention both to itself and to the action that it bifurcates. Importantly, toddlers did not preferentially attend to natural breakpoints. Of interest then, is how the observed patterns of visual fixation in our toddler sample deviate from those observed in adults. Based on the literature, we would expect adults to evince greater attention to breakpoints. Indeed planned comparisons revealed a marginal effect indicating that transitions recruited more attention than motion in the Disrupted Condition, $t(27) = 1.92$, $p = .057$, $d = .37$, and no other significant effects.

Visual inspection of the data revealed 3 outliers in the adult sample with scores on the micro-level measures of at least 3 standard deviations from the mean. The analysis repeated with outliers removed revealed that both pauses ($t(24) = 2.178$, $p = .039$, $d = .44$) and transitions ($t(24) = 2.114$, $p = .045$, $d = .42$) recruited more attention than did epochs of motion in the Disrupted condition (see Figure 4). Thus, both toddlers and adults distributed their attention across the course of the event when pauses corresponded to naturally occurring action boundaries in the intact condition, an effect that is not surprising since, in both cases, attention was recruited preferentially to the disrupted event. When action was disrupted however, toddlers' allocation of attention deviated from that of adults: toddler attention was recruited by disrupting pauses and by epochs of motion whereas adults focused primarily on breakpoints (both disrupting pauses and natural transitions).

Discussion

There are two primary findings from the toddler data. First, as expected, toddlers discriminated intact from disrupted action in the context of events comprised of multiple coarse-grained actions just as they discriminate temporal differences in single, coarse-grained actions (Bahrick et al., 2002; Baldwin et al., 2001). This indicates that young children are sensitive to the temporal structure of events generally and can apply this sensitivity to sequences of coarse-grained action. Our macro-level findings in toddlers are consistent with research that shows infants are able to parse events into distinct actions (Pulverman et al., 2003) and use this information to process dynamic human action. Similar to Friend & Pace (2011), the present findings reveal that toddlers generalize fundamental expectations about motion beyond well-practiced events. Further, adults discriminate intact from disrupted action similarly to the 24-month-olds in our sample.

Second, toddlers' attention was recruited to a greater extent by motion epochs and pauses in the disrupted condition than by natural transitions between actions. Recall that toddlers saw each component action in first, second, and third position in the event sequence and our omnibus analyses revealed no effect of action on visual attention. Consequently, greater attention to motion and pauses relative to transitions in the Disrupted Condition cannot be

attributed to characteristics of any particular action. Rather attention recruited during the pauses in ongoing action suggests that the pauses were salient because they violated the expected continuity of motion. Attention to the disrupting breakpoint is not surprising. One would imagine that children would wonder, “What happened?” when actions were bifurcated thus recruiting attention preferentially to breakpoints that violated expectations of continuous action. Interestingly, however toddlers also attended significantly to the actions themselves (i.e., epochs of motion) relative to the transitions between actions. Thus toddlers treated both pauses and motion as informative when the unfolding of motion lacked predictability.

Our micro-level analyses reveal differences in looking patterns between toddlers and adults. Consistent with the literature (Newtson, 1973; Newtson & Enquist, 1976; Speer, Swallow, & Zacks, 2003), breakpoints (both those that bifurcated action as well as natural action boundaries) preferentially recruited adults’ attention in the Disrupted Condition in contrast to toddlers whose attention was drawn to the disrupting breakpoint and the action itself rather than to natural action boundaries. Unsurprisingly, both toddlers and adults allocated attention relatively evenly across epochs of motion, pauses, and transitions in the Intact condition as the salience of the disrupted event recruited attention away from the intact event. Thus the important findings at the micro-level are the differences in the way that toddlers and adults allocate attention when action does not proceed as expected.

In sum, at a macroscopic timescale, our primary hypothesis that disrupted (relative to intact) events would recruit visual attention was supported. Looking times in both toddlers and adults revealed significantly greater looking toward disrupted relative to intact events across blocks. This pattern was similar across three different iterations of the event itself in which actions occurred in different temporal sequences, revealing a consistent effect across actions and events.

These findings demonstrate that young children readily detect disruptions in the structure of events, and suggest that they parse the stream of motion with respect to this structure. This interpretation is consistent with behavioral evidence suggesting that infants are sensitive to the structure of simple, coarse-grained actions (Baldwin et al., 2001; Reid et al., 2009) and is one of the few studies to extend these results to events comprised of multiple coarse-grained actions (Friend & Pace, 2011).

However, little is known about the features that guide attention allocation within such events, particularly in the presence of a violation of expected motion. The present research addressed this issue by exploring visual fixations at a more fine-grained level of analysis. Our micro-level findings revealed important differences in attention allocation. Whereas toddlers preferentially attended to the bifurcated motion and disrupting pause in the Disrupted Condition, adults attended to breakpoints both within and between actions. Thus, adults treated transitions as particularly salient and informative. Indeed, such a strategy may be optimal for predicting impending action by focusing attention on the event preceding action onset.

Findings in our toddler sample are consistent with previous developmental work showing that young children attend to motion as a salient cue for action interpretation (Abrams & Christ, 2003; Bidet-Ildei, Kitromilides, Orliaguet, Pavlova, & Gentaz, 2013; Kremenitzer, Vaughan, & Dowling, 1979; Rosander et al., 2007). In the only other study, to our knowledge, that has investigated the relative influence of transitions versus actions on looking patterns prior to age 2, Hespos et al. (2010) found that changes in action, rather than in transitions, predicted performance: infants looked significantly longer at novel action/familiar transition compared to familiar action/novel transition segments.

The present findings extend this research by clarifying how specific components of dynamic events guide attention and facilitate the parsing of events that violate expected temporal structure. In toddlers, both disrupting breakpoints and motion were more salient than transitions between actions in disrupted events, suggesting that these features may help to establish units of action within continuous sequences. The relative salience of motion and the bifurcating pauses supports the interpretation that toddlers engaged in coarse-grained processing of the event into component actions. However the adult data suggest that this is not the mature state of the system. When toddlers detect violations of motion, they increase their attention to the perturbation relative to other features of the event whereas adults attend relatively more to features that are stable and predictable. These findings provide evidence for developmental change in attention to stable movement features in event processing.

Other research has shown that young children and adults preferentially describe events in terms of their goal paths rather than their source paths (Lakusta & Landau, 2005). That is, they are more likely to describe a simple event in terms of its end rather than its initial state. For example, when a person walks out of the house and gets into the car, this event would be most likely to be described as *getting into the car* although, in principle, it could be described as *walking out of the house*. Further, Lakusta, Wagner, O'Hearn, and Landau (2007) found that 12-month-olds preferentially encode the end state of an event over its source. This suggests that breakpoints between actions should become salient beginning in infancy. Our adult, but not our toddler, findings are consistent with this notion. How then to explain why toddlers failed to attend to natural action boundaries?

One possibility is that there is a developmental preference for motion over breakpoints. According to this interpretation, motion recruits attention to a greater extent than breakpoints for both predictable and unpredictable events early in development. The Lakusta et al work (2005; 2007) does not contrast motion with transitions in the test phase so it is possible that attention to motion wipes out any effects of attention to breakpoints. Alternatively, pauses that occur unexpectedly may recruit toddlers' attention because they represent periods of relative uncertainty that mark a change in ongoing activity. Thus, children may focus on the action itself as a way of making sense of the unexpected change. Finally, toddlers may simply be unable to inhibit attention to temporal disruptions. According to this interpretation, with development, the domain-general ability to control attention may lead to a more mature strategy such as the one employed by adults who, in addition to looking at the disrupted action, focused on the transitions that predicted its occurrence. One way to tease apart these interpretations would be to conduct a time-course analysis of toddlers' attention to motion and breakpoints in intact events. Because the

present design necessitated presenting intact and disrupted events simultaneously (to assess whether children and adults evinced similar, macro-level, preferences), there exists a dependency between the time-course of attention to the intact and disrupted events. An independent time-course analysis of attention to intact events would help to clarify whether toddlers' attention to motion over breakpoints is unique to events that contain a violation of expected motion.

We have shown that a micro-level time-course approach to looking data can reveal how attention is allocated in real time over the course of an event. This highlights the potential benefit of methods that enable frame-by-frame analyses to better understand the specific features that guide event segmentation and how this changes with development. Future research utilizing a time-course approach across different event types and multiple developmental periods is necessary to clarify the conditions under which specific motion features recruit attention. In the context of unexpected disruptions of motion for example, such an approach would be helpful in clarifying how event processing shifts from a focus on perturbations to a focus on predictable event features. As we have pointed out, violations of expected motion are not uncommon everyday occurrences. Indeed, such violations occur in a number of formal settings as well. Consider the ballerina who hesitates before a turn, or the karate novice who pauses before delivering a chop. It would be particularly interesting to record these naturally occurring violations and acquire time-course data on attention allocation to the features of these events as a means of extending our understanding of how motion events are processed under conditions of surprise or uncertainty.

We return to EST as a means of organizing and interpreting our findings. EST proposes that everyday activity includes substantial sequential dependency, which can facilitate prediction. For example, consider the process of baking a cake. One can make predictions about what will come next based on conceptual features such as inferred goals – if the baker takes out a bowl and a whisk, this implies the goal of mixing. If the agent suddenly stops stirring, EST suggests that the observers will update their event representations to account for this change: the baker might be pausing to rest her arm or may have mixed the batter to her satisfaction. However, within these periods of ambiguity many predictive relationships no longer hold. Thus, increased attention may reflect the relative uncertainty introduced by the disruption of the temporal flow of the event. The present research suggests that, under conditions of event disruption toddlers and adults vary in their allocation of attention to predictable event features.

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Figure 1. Still frame depicting the location of the 1.5-second pause marking the disruption of the Pulley Action from the Disrupted Event (left) and the completion of the Pulley Action from the Intact Event (right).

Figure 2. Illustrative temporal scale for epochs. Blue bars indicate motion epochs, pink bars indicate pauses, and green bars indicate transition epochs.

Figure 3. Toddler looking patterns during Motion, Pauses, and Transitions by Condition. Note: Bars with the same script differ at $p < .05$.

Figure 4. Adult looking patterns during Motion, Pauses, and Transitions by Condition. Note: Bars with the same script differ at $p < .05$.

Table 1
Epoch Durations (seconds) for Intervals of Motion, Pauses, and Transitions in Intact and Disrupted Events.

Epoch	Intact Events			Disrupted Events		
	Sequence 1	Sequence 2	Sequence 3	Sequence 1	Sequence 2	Sequence 3
1. Motion (Action 1)	2.0	1.5	2.7	2.0	1.5	2.7
2. Pause (Action 1)	1.5	1.5	1.5	1.5	1.5	1.5
3. Transition (Action 1)	1.7	1.7	1.7	1.7	1.7	1.7
4. Motion (Action 2)	1.5	2.7	2.0	1.5	2.7	2.0
5. Pause (Action 2)	1.5	1.5	1.5	1.5	1.5	1.5
6. Transition (Action 2)	2.0	2.0	2.0	2.0	2.0	2.0
7. Motion (Action 3)	2.7	2.0	1.5	2.7	2.0	1.5
8. Pause (Action 3)	1.5	1.5	1.5	1.5	1.5	1.5

Note. Epoch values are defined for all three sequences (1, 2, 3) in the intact and disrupted conditions. Epochs 1, 4 and 7 are comprised of intervals that precede and follow the pause in disrupted events, and thus, are summed across the motion prior to, and after, the pause. The action sequences were 14.5 sec in duration from the onset of action 1 to the offset of action 3 however the epochs sum to 14.4 due to rounding. Final epochs of motion, pauses, and transitions were collapsed across sequence and action.