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Attending to What Matters: Flexibility in Adults’ and Infants’ Action Perception

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Abstract

Action perception is selective, in that observers attend to and encode certain dimensions of action over others. But how flexible is action perception in its selection of perceptual information? One possibility is that observers consistently attend to particular dimensions of action over others across different contexts. Another possibility, tested here, is that observers flexibly vary their attention to different dimensions of action based on the context in which action occurs. We investigated 9.5-month-old infants’ and adults’ ability to attend to drop height under varying contexts: aiming to drop an object into a narrow versus a wide container. We predicted differential attention to increases in aiming height for the narrow container versus the wide container, as an increase in aiming height has a differential effect on success (i.e., getting the object into the container) depending on the width of the container. Both adults and infants showed an asymmetry in their attention to aiming height as a function of context: in the wide container condition increases and decreases in aiming height were equally detectable, while in the narrow container condition observers more readily discriminated increases over decreases in aiming height. These results indicate that action perception is both selective and flexible according to context, aiding in action prediction and infants’ social-cognitive development more broadly.

Keywords

intention; attention; action prediction; perceptual selection; motor representations; action observation

The ability to process and derive meaning from human actions is a tremendous feat: human actions are dynamic and complex stimuli, and contain a great deal of perceptual information that an observer could attend to and encode. Imagine, for example, observing the complex actions of a barista as she prepares your morning espresso. As she rapidly flits from one device to another, each action varies with respect to the objects manipulated, the type of hand contact used, and the speed and trajectory of motion. Given this complexity, how does the perceptual system reduce the complexity of human action in order to derive meaningful information: for instance, determining when your drink is ready?

One solution to this problem is that action perception is selective in nature. That is, not all aspects of action are attended to or encoded equally. First, past research has established that

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in terms of observers' memories for events, adults and infants tend to remember an actor's underlying goal or action outcome over and above the manner in which this outcome was achieved. For example, when describing someone brushing their teeth, adults largely focus on crucial goal outcomes, such as picking up the toothpaste, and spare details regarding the means by which that goal was fulfilled, such as whether the actor used his or her right or left hand (Baldwin & Baird, 2001; Reed, Montgomery, Schwartz, & Palmer, 1992). Similarly, by 5 to 6 months of age, but not beforehand, infants who are visually habituated to a simple reach and grasp event show greater encoding of the relation between the actor and her goal object over and above the way in which the goal was achieved (e.g., the spatial trajectory her arm took through space; Sommerville, Woodward, & Needham, 2005; Woodward, 1998). Moreover, infants' selective attention to actor-goal object relations over the manner in which the goal is achieved becomes increasingly robust over the first year of life (Sommerville & Woodward, 2005; Woodward & Sommerville, 2000), driven by infants' developing ability to perform goal-directed actions (Sommerville, Hildebrand, & Crane, 2008). These findings establish that goal information is prioritized over means information in infants' and adults' representations of actions.

Second, at a more fine-grained level, both adults and infants prioritize perceptual dimensions of action that specify or constrain upcoming action outcomes. For example, adult and infant observers selectively attend to how an actor's hand contacts objects: even when the goal of the action remains unchanged, both adults and 10-month-old infants find changes to hand contact information more salient than changes to spatial trajectory or temporal information in action (Loucks & Baldwin, 2009; Loucks & Sommerville, 2012a). For adults, this is true even when changes to spatial information are objectively larger than changes to hand contact information (Loucks & Baldwin, 2009; Loucks, 2011). This aspect of selectivity also undergoes development during infancy: 4-month-old infants attend equally to hand contact, spatial trajectory, and temporal information in action, while 10-month-old infants have narrowed their attention and selectively focus on hand contact information (Loucks & Sommerville, 2012a). This focus on hand contact may aid in processing upcoming actions, as the type of hand contact used on an object has functional consequences: it constrains the possible future actions one can take with that object. For instance, grasping a glass of water with the hand over the rim precludes the possibility of drinking from it. In support of this hypothesis, we found that 10-month-old infants are sensitive to the functional consequences of different grasp types with respect to how these outcomes constrain possible future actions (whether an object could be picked up or not, Loucks & Sommerville, 2012b).

The aforementioned findings suggest that infants' and adults' representations of action prioritize information about actor goal-object relations and hand contact information specifying upcoming actions, over and above other types of information such as spatial trajectory information, location information, and temporal information. However, in many of these studies, spatial trajectory information, location information and temporal information were not relevant to the actor's goal or the intended action outcome. The question addressed in this paper concerns whether there are contexts in which infants and adults increase their attention to action information that is often diminished or neglected. Thus, the current study is aimed at addressing the flexibility of adults' and infants' selective attention in action perception.

There are at least two possibilities regarding the nature of infants' and adults' selective attention. One possibility is that both adults and infants consistently diminish or fail to encode information regarding spatial trajectory information, location information and temporal information because such information is not typically relevant to the task of action perception: the identification of an actor's goals. A second possibility is that adults and/or infants may be more flexible in their encoding of different dimensions of action, and vary what they attend to and encode based on the context in which action occurs, particularly when such information *is* relevant to identifying action outcomes. Such flexible selection of relevant information would be highly adaptive, given the sheer amount of perceptual information available to process in human action, combined with countless variations in actions and context. This is especially true for developing infants, whose limited information-processing capacities put constraints on the amount of perceptual information they can attend to and encode. Heightening attention to relevant properties flexibly on the basis of context would help ensure that infants are focused on the most useful information for learning from others' behavior.

Human actions are highly salient to infants, and early in development are even more salient than faces (Bahrick & Newell, 2008; Bahrick, Gogate, & Ruiz, 2002). However, to date few studies have examined flexibility within action perception. Woodward and Sommerville (2000) investigated flexibility in 12-month-old infants' interpretation of human action. They found that infants interpreted the same action (touching the lid of a box) differently, depending on whether the action causally enabled the achievement of a subsequent goal (retrieving a toy from inside the box) or not (retrieving a toy that was outside of the box; see also Sommerville & Woodward, 2005, for similar evidence with a cloth-pulling sequence). The current study addresses a related, but distinct, question: whether adults and infants vary what dimensions of action they attend to and encode as a function of context. To our knowledge, no previous research has addressed this specific issue.

To address whether infants' and adults' attention to perceptual dimensions varies according to context, the current research investigated infants' and adults' perception of an event in which an actor aimed to intentionally drop an object into a container. There are (at least) two perceivable variables that influence whether an object will successfully land in the container: the height from which the object is dropped, and the width of the container. The higher the release point, the harder it will be for the actor to precisely aim the drop location, thus the landing point of the drop will be more variable for high release points than for low release points. Importantly, this increase in error is due to the increased difficulty in targeting, and not the physical process of dropping. If the target container is wide, such variability in aiming is inconsequential: the object is still likely to land somewhere in the container, given its large width. However, if the target container is relatively narrow, such variability in aiming may exceed the width of the container and therefore influence the success of the drop. Thus, the exact same increase in aiming height is differentially important for predicting the success of a drop into a wide versus narrow container. If observers recognize the differential importance of the same change in aiming height across the two contexts to the action outcome we would predict heightened attention to increases in aiming height for narrow container events but not for wide container events.

Such a prediction relies on the assumption that an observer's goal is to predict the outcome of a given action. Research supports this assumption both in adults and infants. When watching an actor grasp and move objects to a new location, both adults and infants produce anticipatory saccades to the goal object and the new location prior to the arrival of the actor's hand (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Flanagan & Johansson, 2003; Kanakogi & Itakura, 2011). Infants also appear to form expectations regarding the outcome of actions (Daum, Prinz, & Aschersleben, 2011; Daum, Vuori, Prinz, & Aschersleben, 2009). For instance, Daum et al. (2009) demonstrated that 9-month-old infants could infer what kind of grasp an actor was going to use on an object based solely on the grip aperture of the hand. Note that prediction in such previous research relies on tracking the actor's hand, whereas for dropping an object into a container, prediction relies on integrating spatial information about the object and the distal container. We hypothesize that observers utilize information that is relevant to the outcome at hand, regardless of the nature of that information (hand shape vs. spatial information). Thus, if observers are attempting to predict the outcome of a given action, we hypothesize that they will attend selectively to changes to the action that are likely to affect the outcome as constrained or defined by the surrounding physical context.

The goal of the current research was to evaluate whether both adults and infants flexibly vary what they attend to given the context in which action occurs. We tested infants and adults in the current work for two reasons. First, existing work suggests that there are developmental changes both in infants' selective attention to various dimensions of action over the first year of life (Loucks & Sommerville, 2012a; Sommerville et al., 2005; Sommerville & Woodward, 2005), and in their ability to predict the goal of particular actions (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Kanakogi & Itakura, 2011), which are tied to their ability to produce particular goal-directed actions. Thus, we tested 9.5-month-old infants who have just begun to attain competence at aiming to drop and throw objects (Ruff, 1984) in order to investigate the earliest emergence of flexibility in infants' attention to dimensions of human action given the context. Second, comparing adults and infants allowed us to examine continuity in the flexible nature of action perception across the lifespan. Although by 10 months of age infants are similarly biased as adults to selectively attend to hand contact information (Loucks & Somerville, 2012a), there may be differences in flexibility between adults and infants as a result of infants' more limited experience with action generally. In addition, for both age groups, no previous research has examined selective attention to properties of action for aimed dropping actions[1].

A secondary goal of the current studies was to assess whether adults' and infants' flexibility in action perception is related to their motor performance. A considerable body of research indicates that action perception and action production in adults share a common underlying processing system (Brass, Bekkering, & Prinz, 2001; Decety et al., 1997; Flanagan & Johansson, 2003; Prinz, 1997; Rizzolatti & Craighero, 2004). Likewise, evidence for such common coding of action perception and production has also been documented in infancy (Cannon et al., 2012; Daum et al., 2011; Gredebäck & Kochukhova, 2009; Southgate, Johnson, El Karoui, & Csibra, 2010), along with evidence that infants' motor experience can actually *cause* changes in action perception (Sommerville et al., 2008, 2005). In the current studies, we specifically investigated whether perception of aimed dropping in another person might be related to an individual's motor ability to perform aimed drops. As 9- to 10-month-old infants have only recently gained experience with aimed dropping, their attention to aiming height may also be related to their individual proficiency with this action. Exploring a possible action perception/production link in infancy is important as it may provide greater insight into the developmental process by which infants actually gain flexibility in perception. In addition, comparing adults and infants on similar tasks allows us to examine whether these two groups use similar or different underlying processes for this purpose.

In Experiment 1, we designed a task in which adult participants viewed actors aiming to drop objects from various heights into either a narrow or wide container, and were asked to detect both upward and downward changes in aiming height. We predicted that participants would be significantly more sensitive to detecting upward changes relative to downward changes in the case of dropping into a narrow container. This comparison of upward and downward changes allowed us to compare performance at detecting height changes that were more relevant to predicting the outcome (increases) with height changes that were less relevant to predicting the outcome (decreases). We further predicted that this differential

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[1] We use the term aimed dropping here to distinguish this action from accidental dropping, which lacks the intentional component.

sensitivity to upward versus downward changes would not be observed in the case of dropping into a wide container, since neither height change would have an impact on predicting the outcome.

In a separate task, we also assessed participants’ own ability to aim and drop an object into a narrow container from various heights. Our impetus was twofold. First, we wanted to assess the possible relation between aiming performance and perception. To date, no research has specifically investigated whether a relation between perception and production exists for aimed dropping actions. Second, we wanted to provide direct evidence that increasing aiming height does, in fact, increase targeting error.

In Experiment 2, we modified the perceptual task used in Experiment 1 for infant participants, to examine whether 9.5-month-old infants’ attention during action observation is similarly flexible in the service of action prediction. To the extent that sensitivity to aiming height in precision aiming is related to aimed dropping production, this age group may have enough hands-on experience with aimed dropping to demonstrate the predicted flexibility in perception. In addition, we also investigated whether individual variability in infants’ motor abilities was related to their perception of other's aimed dropping. Of particular interest is whether there are changes between infancy and adulthood in the flexibility of selective attention in either direction.

Experiment 1

Experiment 1 assessed whether adults modulate their attention to aiming height during aimed dropping observation as it relates to action prediction. We predicted that adults would be better at detecting upward versus downward height changes in the context of dropping into a narrow container, and would not display such differential sensitivity in the context of dropping into a wide container. We also separately assessed participants’ own ability to intentionally drop an object into a container, in order to provide direct evidence that increasing aiming height increases targeting error, in addition to investigating the relation between aimed dropping production and perception.

Method

Participants

Participants were 32 undergraduate university students (10 male). Half of the participants were assigned to the narrow container condition, and the other half were assigned to the wide container condition. All participants participated in two tasks: the perception task and the dropping task. One participant's data was replaced as this individual's mean accuracy on the perception task was three standard deviations below the mean. Participants received partial course credit as compensation for their participation.

Stimuli

Perception Task—The stimuli for the perception task consisted of 30 videos of aimed dropping actions: Three actors (one female, two males) × two containers (narrow and wide) × five aiming heights. The narrow container was white, 7.1 cm at its widest diameter, and stood 5 cm high. The wide container was green, 14.6 cm at its widest diameter, and stood 6.7 cm high. The five aiming heights were relative body locations: hip height (hip), middle torso height (torso), shoulder height (shoulder), forehead height (head), and over the head height (above). The aiming heights were identical between the two container conditions. The dropped object was a small brown beanbag, 3.2 cm in diameter. At the outset of each video, the actor stood with the beanbag in their right hand and the container placed midline on the floor. The actor then lifted the beanbag to one of the five aiming heights and successfully dropped it into the container. Actor movements were synchronized to a metronome, to ensure identical pace and overall length (3 seconds each).

From each of these videos, 30 still frames were also selected. Each still frame depicted one of the actors holding the beanbag above one of the containers at one of the five aiming heights.

Dropping Task—The stimuli for the dropping task included the same narrow container and small brown beanbag used in the perception task. During the task, the container was placed in different positions on a 12 × 12 inch craft mat, in order to increase the number of trials while reducing the effect of practice. Nine such positions were demarcated with stickers, placed on the mat at nine equally-spaced points (five inches vertically and horizontally apart from one another).

Design & Procedure

All participants completed the perception task followed by the dropping task. In the perception task, on each trial they viewed a dropping video followed by a still frame, and were asked to verify whether the still frame was something that they saw in the immediately previous video or not. In the subsequent dropping task, participants made several attempts to drop a small beanbag into a narrow container from various heights. Both tasks took place in the same room.

Perception Task—For the perception task, condition (narrow vs. wide container) was varied between-subjects, with equal numbers of participants assigned to conditions. We elected to use a between-subjects design, so that participants' perception would not be influenced by seeing the other container size. For instance, comparing the two container sizes might magnify the hypothesized effect. In this way, a between-subjects design allowed for a more stringent test of the possible effect. Furthermore, a between-subjects design reduced participants' overall time commitment. Thus, each condition only featured drops into one of the containers, made by the three actors from the five different aiming heights (15 videos total).

On a trial, a video was played, followed by a 2 s blank screen, and then a still frame was presented. The still frame remained on the screen until participants responded, after which the next trial was initiated. Half of the trials were same trials, in which the still frame represented the same aiming height displayed in the video, and half were different trials, in which the still frame represented one of the other four heights. The order of presentation of the trials was completely random, with the exception that no actor be repeated twice in a row. There were a total of 120 trials for each condition.

A laptop computer was used to present stimuli and record participants' responses on a 13.5 × 7.5 inch display. From the participants' seating position, videos subtended approximately 16 × 12 deg of visual angle. Psychtoolbox (Brainard, 1997) was used to present trials and record responses.

Dropping Task—The perception task always preceded the dropping task. Because we hypothesized that participants would fare poorly with higher height drops in the dropping task, we did not want their potential awareness of this aspect of their motor performance to influence their perception of higher height drops during the perception task.

In the dropping task, participants attempted to successfully drop the same beanbag into the same narrow container from the same five aiming heights, at nine equally-spaced positions on the mat (45 trials total). Trials were grouped into three blocks. In each block, participants made three drops at a particular height before moving on to another height. Height and position combinations were pseudo-randomly ordered such that no position was repeated successively.

On each trial, the participant raised the beanbag to one of the specified heights. The experimenter then placed the container on one of the nine positions on the mat that was placed midline on the floor. The participant aimed the beanbag over the container and attempted to drop it in. The experimenter reminded participants not to accidentally lower their hand during the aiming process, and ensured that no participant did so. The experimenter coded whether each drop was successful or not. Only drops in which the final position of the beanbag was inside the upright container were considered successful.

Procedure—Following informed consent, participants were seated in front of the laptop for the perception task and provided instructions. They were told that each trial they would see a video and a still frame of action, and would be asked to verify whether the still frame was something that they saw in the video or not. They were asked to make their responses as quickly and accurately as possible, using assigned mouse buttons. Following the perception task, all participants took part in the dropping task.

Results & Discussion

Preliminary analyses revealed no effect of gender in the perception task or dropping task, and thus this variable was excluded from further analyses. In addition, participants in the narrow and wide container conditions did not differ in their overall accuracy during the perception task, $t(30) = 0.80$, $p = .43$, or the dropping task, $t(30) = 0.78$, $p = .44$.

For the perception task, mean accuracy rates (proportion correct) were calculated for all different trials in which the height change was one step upward (e.g., from shoulder to head), and one step downward (e.g., from shoulder to torso). These mean upward and downward accuracy rates reflect the finest degree of height discrimination that we obtained from participants in the perception task.

Figure 1 displays the mean accuracy rates by condition. A 2 (height) × 2 (condition) mixed ANOVA revealed a significant interaction between height and condition, $F(1,30) = 4.67$, $p = .039$, $\eta^2 = .14$. As predicted, participants in the narrow container condition were significantly more accurate at detecting upward changes over downward changes, $t(15) = 2.66$, $p = .018$, $d = 0.66$, while participants in the wide container condition were not differentially sensitive to the two height changes, $t(15) = 0.72$, $p = .49$.

For the dropping task, the average proportion of hits was calculated for each height. These data are presented in Figure 2. A planned contrast analysis revealed a significant linear trend, $F(1,31) = 41.91$, $p < .001$, $\eta^2 = .58$, indicating that accuracy decreased with increased aiming height. Planned comparisons also revealed a significant decrease in the torso to shoulder transition, $t(31) = 5.31$, $p < .001$, $d = 0.94$, and the head to above transition, $t(31) = 3.49$, $p = .001$, $d = 0.62$. Additional transitions were not significant, all p's > .05. Thus, as predicted, participants had more difficulty aiming as drop height increased.

Finally, we also assessed the relation between aimed dropping production and perception. Across both conditions, mean accuracy during the dropping task was significantly and positively correlated with mean accuracy during the perception task, $r(31) = .37$, $p = .035$, two-tailed.

The results of this experiment highlight flexibility in action perception, and indicate that adults' attention to perceptual dimensions of action is modulated as a function of context.

Aiming to drop an object from higher up has consequences: The error in targeting the drop increases, as the results from the dropping task confirmed. As the only difference between the narrow and wide container conditions was the size of the container, we assume that the reason adults devote more attention to upward over downward changes in height in the narrow but not the wide condition is due to the fact that this perceptual information is more informative for predicting the outcome of the action in the narrow container condition. Importantly, any simple perceptual explanation about an upward bias in perception cannot explain these data as such a bias would also differentiate upward and downward changes in the wide container condition.

This dimension of motor performance influences adults' perception of others' action; in fact, the current experiment revealed a relation between aimed dropping production and perception. The higher an individual's skill at aimed dropping, the more sensitive they were at detecting changes in the aiming height of another individual (upward or downward). However, adults appear especially sensitive to this dimension when the context pulls for it – only in the narrow container condition were adults more sensitive to upward relative to downward spatial changes.

Experiment 2

Having identified that action perception is flexible in the service of prediction in adults, in Experiment 2 we examined whether infants' action perception is similarly flexible in nature. Evidence for flexibly selective attention to relevant action dimensions would highlight the sophisticated nature of infants' action perception; such an attribute would allow infants to focus on information that is directly relevant to predicting an actor's ongoing actions, reducing the demand on infants' processing abilities. We chose to examine this process in 9.5-month-old infants, as infants at this age have recently gained proficiency with intentionally dropping objects in their everyday life (e.g., dropping "games" in which the infant intentionally drops an object for their parents to retrieve; Ruff, 1984), and thus should be familiar with this action. Infants were habituated to aimed dropping into either a narrow or wide container, and then shown two test events: aiming from a lower and a higher height. Our predictions were that infants in the narrow container condition would look longer at the higher height event over the lower height event, while infants in the wide container condition would not differentiate between the events.

As with adults in Experiment 1, we also examined whether individual variability in infants' motor abilities was related to their flexibility in action perception. We assessed infants' motor skills using a parental questionnaire: the Motor Abilities Checklist (MAC; see the Appendix). The items on the MAC were adapted from the motor portion of the Bayley Scales of Infant Development (Bayley, 1993). The MAC allowed us to get both a global snapshot of infants' gross motor development between 9 and 10 months, as well as more specific information about infants' aimed dropping abilities. To assess infants' aiming abilities, parents were asked whether their infant could throw a ball[2]. Because intentional dropping and throwing are both aiming events, we predicted that infants' throwing ability would be positively correlated with their preference for the higher height drop over the lower height drop. However, we predicted that this relation would be unique to the narrow container condition, given that only infants in the narrow condition were predicted to have enhanced attention to increases in aiming height.

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[2] We were concerned that parents might misinterpret a question about their infants' dropping behavior to include events of accidental dropping. Thus, we asked parent to report on their infants' throwing behavior instead.

Note that we are predicting a more specific motor relation here relative to the broad motor relation we observed in Experiment 1. The reason for this difference is due to the relative degree of experience across the two populations. In Experiment 1 we were assessing adults' relative skill with aimed dropping, which is something adults have a great deal of experience with. Since all adults can perform this action, it may only be those with particular skill with this action who are broadly sensitive to drop height. However, with infants we are assessing whether they *possess* a particular skill or not. As infants who can throw will have considerably less experience with aiming compared to adults, they may have a higher threshold for detecting changes in aiming height than adults – that is, perhaps only "risky" height changes (increases above narrow containers) capture attention compared to "safer" height changes (increases above wide containers).

Finally, we also assessed the relation between infants' overall motor development and infants' looking time preferences, in order to rule out the possibility that any relations between infants' perception of aimed dropping actions and production of throwing actions were driven by overall motor development or maturational level. If this understanding is related to specific experience with throwing, then it should not also be related to additional motor achievements.

Method

Participants

Participants included 26 9.5-month-old infants (11 females, M_{age} = 9 months 21 days, range = 9 months 11 days to 9 months 29 days). Half were assigned to the wide container condition, and the other half were assigned to the narrow container condition. All infants were full term (at least 37 weeks gestation), typically developing, and from a large metropolitan area. Participants were recruited from a database maintained by the university at which the research was conducted. Based on parental report of race/ethnicity, 22 infants were classified as White, 1 as Black/African American, and 3 as mixed or unlisted ethnicity; 1 self-classified as being of Hispanic ethnicity. An additional 11 infants were tested but excluded from the final sample due to: failure to habituate (n = 7), excessive fussiness or lack of attention (n = 1), having a test trial looking time beyond 2.5 standard deviations of the mean (n = 1), or experimental error (n = 2). Infants received a small toy for their participation.

Stimuli

Stimuli included a total of six videos. For both the wide and narrow container conditions there was one habituation video, one lower height video and one higher height video. These videos can be viewed online as part of the supplemental material for this article. All videos were recorded digitally at 30 frames per second, imported and edited on a computer, and exported as Quicktime files without sound. All of the videos were equated in length (8 seconds).

In each video, a smiling actor was seated at a table, centered in front of a narrow or wide transparent glass container, with a small purple elastic ("Koosh") ball beside the container to his right. The narrow container was 11.4 cm at its widest diameter, and stood 4.5 cm tall, and the wide container was 22.9 cm at its widest diameter, and stood 10 cm tall. For the habituation video in each condition (there were two – one for each condition), the actor picked up a toy, raised it to a standard aiming height above the container, and then successfully dropped it in. The actor ensured that the standard height was identical across the two container conditions by raising the ball to a pre-marked visual point on the wall behind the camera. This same strategy was used to ensure that the changes in height in the higher and lower height videos were identical across container conditions. For both of these videos, the only difference relative to the habituation video was that the toy was aimed from a higher or lower height. The actor moved in sync with a metronome during recording of the videos to equate the timing of each action segment.

Motor Abilities Checklist

Parents reported their infant's gross motor skills using the MAC prior to the experiment. The MAC consisted of 24 items, adapted from the motor portion of the Bayley Scales of Infant Development (Bayley, 1993), and can be found in the Appendix. Each item asked parents to report on whether their child could engage in a particular motor behavior, such as “Can your child maintain a steady sitting position?”, or “Can your child throw a ball?” Items were ranked according to their typical emergence in development (e.g., walking ranked higher than self-sitting), such that the highest items characterized the most advanced motor skills (e.g. “Can your child stand on one foot with help?”). For each item, parents responded “Yes” if they had observed the behavior, “Maybe” if they had not observed the behavior but believed it was within their infant's capabilities, and “No” if they had not observed the behavior and did not believe it was within their infant's capabilities. Responses were then numerically coded, with “Yes” coded as 1, “Maybe” coded as 0.5, and “No” coded as 0.

The purpose of administering the MAC was twofold: 1) to assess infants’ overall motor development, and 2) to assess whether or not infants could throw. With regards to the former, two scores were calculated: a sum of all items, as well as the highest (most advanced) item number checked.

Design & Procedure

Infants were seated in their parent's lap approximately 75 centimeters from a computer monitor which rested on a black table (61 × 98 cm). From where infants were seated, the video stimuli subtended approximately 20.6 × 16.4 degrees of visual angle. Infants and their parents and the table were surrounded by black curtains on three sides, which reached to the wall behind the infants and parent and up to the ceiling. A camera hidden behind the curtains recorded infants’ looking behavior. Parents were instructed not to look at the screen and to remain quiet and neutral throughout the session.

Stimulus presentation and looking time calculations were controlled by a custom program utilizing Psychtoolbox (Brainard, 1997). Once the program started, the session was entirely controlled by infants’ looking behavior. At the beginning of each trial, an attention-getting stimulus was displayed on the screen (a flashing red and white checkerboard accompanied by a chime) in order to encourage infants to look at the screen. Once they were looking, the video for the trial began playing. The video for a trial looped continuously, with a 0.5 second black screen inserted between successive presentations. The video played until two criteria were met: 1) the infant had looked for a cumulative total of at least four seconds (long enough to encode the aiming height in each video), and 2) the infant looked away continuously for more than two seconds. If neither of these criteria were met, the video played for a maximum of 10 presentations (80 seconds). At the end of a trial, the next trial began immediately, again with the attention-getting stimulus.

Each condition began with a habituation phase, in which the habituation video for that condition was shown each trial, and infants’ look durations were measured. Infants viewed the habituation trials until the average looking on three consecutive trials was half of the average looking on the initial three trials, or until a maximum of 10 habituation trials. The test phase began immediately after the habituation phase. In the test, each of the two types of test videos for that condition was shown twice, in alternating order (order of alternation was fully counterbalanced across infants).

A trained observer, who was blind to condition and to the particular events displayed on the screen, coded infants' looking online by depressing a keyboard button when the infant was looking at the screen. Following the experiment, a second observer recoded looking times offline from video. Agreement between the two observers was high (86%).

Results

Looking time data are reported as means, for ease of interpretation. However, all statistical analyses were performed on natural log transforms of the looking time data, due to significant positive skew. Because preliminary analyses revealed no significant effects of either gender or test trial order on looking times, these variables were not considered further. Looking times during the habituation phase were first analyzed to ensure that there were no differences between the two container conditions that could contribute to looking time differences during the test phase. Infants in each condition did not differ in their average looking across the last three habituation trials or in the number of habituation trials needed to reach criterion, both *p*'s > .05, indicating that they were equally interested in the habituation events. Finally, data from the MAC confirmed that the infants in each condition were equated in their overall motor development, as infants did not differ in the sum of items, or the highest item checked, or in throwing ability, all *p*'s > .05.

In order to determine whether infants' displayed significant recovery to the test events following habituation, mean looking times during the test trials (two for each type) was compared against mean looking to the last two habituation trials. In the narrow container condition, infants showed no significant recovery to the higher height event, $t(12) = 0.03$, $p = .98$, but showed significant further habituation to the lower height event, $t(12) = 2.38$, $p = .035$, $d = 0.66$. In contrast, infants in the wide container condition showed no significant recovery to either the higher or lower height event, $t(12) = 0.75$, $p = .47$, and $t(12) = 0.69$, $p = .50$, respectively.

However, our primary analysis concerned potential differential attention to the two height changes in each condition. Total looking times to each of the change videos were averaged across pairs of test trials. Figure 3 displays these mean looking times at test in each condition. A 2 (test trial) × 2 (condition) mixed ANOVA revealed a significant interaction between test trial and condition, $F(1,24) = 5.00$, $p = .035$, $\eta^2 = .17$. Planned follow-up analyses confirmed that, as predicted, infants in the narrow container condition looked significantly longer at the higher height event over the lower height event, $t(12) = 2.36$, $p = .036$, $d = 0.66$, while infants in the wide container condition did not differentiate between the two change types, $t(12) = 0.20$, $p = .85$. Although it is difficult to compare the two tasks, note that the size of this effect was highly similar (in fact, identical) between adults and infants.

Motor Abilities Checklist

Overall, throwing ability was significantly and positively correlated with the highest item checked on the MAC, $r(23) = .51$, $p = .009$, largely due to the fact that the throwing item itself was high on the list. However, throwing was not significantly correlated with the sum of items on the MAC, $r(23) = .14$, $p = .51$. In order to assess relations to infants' perception of others' aimed dropping, we calculated each infant's higher height preference score: their mean looking time to the higher height event minus their mean looking time to the lower height event. We then correlated this variable with three variables obtained from the MAC: throwing ability (item 20), the sum of scores, and the highest item checked. In order to ensure that age was not a confounding factor in assessing these relations, age was partialled out for all analyses. As predicted, throwing was significantly and positively correlated with preference for the higher height event for infants in the narrow container condition, partial *r*(9) = .60, *p* = .048. This same correlation was not significant for infants in the wide container condition, partial *r*(10) = .01, *p* = .97. Thus, as infants' throwing ability increased, their preference for the higher height event in the narrow container condition also increased. In contrast, infants' overall motor development was independent of their looking time preferences. The sum of scores was not significantly correlated with looking time preferences in either the narrow or wide condition, *r*(9) = .11, *p* = .74, and *r*(10) = .26, *p* = .41, respectively. In addition, the highest item checked was not significant correlated with looking time preferences in either the narrow or wide container condition, *r*(9) = .34, *p* = .30, and *r*(10) = .15, *p* = .64, respectively.

Within each condition, we further divided infants into two groups based on whether or not parents had witnessed or believed their infant to be capable of throwing. We called infants whose parents had responded "Yes" or "Maybe" to the throwing item "throwers" and infants whose parents responded "No" to the throwing item "non-throwers". There were *n* = 8 throwers and *n* = 4 non-throwers in the narrow container condition, and *n* = 5 throwers and *n* = 8 nonthrowers in the wide container condition. Mean looking times to the test trials for throwers and non-throwers in each condition are plotted in Figure 4. In the narrow container condition, only throwers significantly preferred the higher height event over the lower height event, *t*(7) = 4.01, *p* = .005, *d* = 3.03, while non-throwers did not, *t*(3) = 0.58, *p* = .61. In the wide container condition, neither the throwers or the non-throwers preferred the higher height event, *t*(4) = 0.25, *p* = .82 and *t*(7) = 0.14, *p* = .89, respectively.

Given that 1) only throwing, and not infants' overall motor development, was significantly related to infants' looking time preference, and 2) that this relation was unique to the narrow container condition, suggests we were assessing a similar relationship between aimed dropping perception and performance, as we did with adults in Experiment 1.

General Discussion

The current experiments demonstrate that observers increase their attention to perceptual information that is relevant to predicting action outcomes, and that this attribute of action perception is present by 9.5 months of age. Both adults and infants were more sensitive to upward relative to downward changes in aiming height in the context of dropping into a narrow container. We believe this is because they were trying to predict the outcome of the drop, and the increased height increased the possibility of a miss, while the decreased height did not. This process is also flexible with respect to context: Neither age group was more sensitive to the upward changes in the context of dropping into a wide container – even though it was the identical change in aiming height – because it did not influence the probability of missing, and thus was not as relevant to the outcome.

The difference between container conditions is particularly important in interpreting these results. Had observers been more sensitive to upward versus downward changes in the wide container condition, the results could have been due to some kind of perceptual bias for upward motion changes, or for changes in information contained in the upper visual field. However, the same upward changes were not detected with any increased accuracy in the wide container condition, as they were in the narrow container condition. Because the only difference between these conditions lay in the difficulty in aiming the object, we hypothesize that the increased attention to upward changes in the narrow container condition reflects the increased relevance of this information to predicting the outcome of the dropping action.

This is not to say that decreases in height are not equally informative in making a prediction. When the actor decreases the aiming height, an observer can predict with more certainty that the object will end up in the container. However, this does not change the categorical nature of the prediction in the same way an increase does (i.e., success to potential failure). We believe that the increases in aiming height in the case of dropping into a narrow container are attended to with more fidelity because they lower the confidence in predicting a successful outcome. There may be situations in which a decrease in aiming height may similarly shift predictions categorically: for instance, if an actor previously missed the container, then a decrease in height may shift predictions in the opposite direction, and be attended to with greater fidelity.

The results from adults also indicate that perceptual sensitivity in the observation of aimed dropping actions is related to motor skill at aimed dropping. This novel finding is consistent with research indicating that action perception and production share a common underlying processing system (Brass, Bekkering, & Prinz, 2001; Decety et al., 1997; Prinz, 1997; Rizzolatti & Craighero, 2004), and the notion that perception and action are tightly intertwined (Gibson, 1979). The fact that we observed a relation between aimed dropping production and perception further bolsters the claim that the current findings are not due to a simple perceptual bias, as there is no reason to expect such a relation in that case. Note that the relation was observed in both container conditions: it is a general relation between aimed dropping production and perception, and not tied to the particular modulation in attention we observed in the narrow container condition. However, we believe that the observed modulation in attention was done in the service of prediction, and research indicates that common coding of production and perception aids in action prediction (Blakemore & Frith, 2005; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Knoblich & Flach, 2001; Sebanz & Shiffrar, 2009; Wöllner & Cañal-Bruland, 2010). It is possible that the increased sensitivity to aiming height in the narrow container condition stems from observers' prior experience with aimed dropping; future research should further evaluate this causal claim.

As infants in this experiment had recently gained proficiency with purposeful dropping in their everyday life, their perception of aimed dropping may also have been influenced by their motor abilities. Although we did not assess infants' aimed dropping abilities in Experiment 2, we did observe a significant correlation between infants' preference for the higher height event in the narrow container condition and parental report of throwing behavior. Further, we also found that infants who could throw were a driving factor in the overall significant preference for the higher height drop in the narrow container condition. One difference from Experiment 1 is that the observed relation between motor performance and perception was specific to the modulation of attention in the narrow container condition. We believe that because infants are considerably less experienced than adults with throwing and dropping, the link between production and perception is only observable for especially engaging perceptual events at this age (i.e., increasing the height of a narrowly aimed drop but not a wide drop). However, it is also possible that a more direct measure of dropping ability in infancy might yield different results, more similar to the broad relation we observed with adults in Experiment 1. In any case, we believe the relation we did observe highlights the emergence of the same performance/perception process in infants that we observed for adults. Indeed, links between action production and perception have been documented in infancy (Cannon et al., 2012; Daum et al., 2011; Longo & Bertenthal, 2006; Sommerville et al., 2005). Such a link could serve as a powerful learning mechanism in infancy, and may ultimately engender flexibility in infants' perception of others' actions.

Although there are superficial differences in the motoric actions required to execute a throw versus a drop, on a deeper level the underlying goals of the actions are the same: to displace an object (either vertically or horizontally). The fact that the relation was specific to throwing behavior and not age or overall motor development, and was only observed in the narrow container condition, suggests that this relation may underlie infants' flexible attention during action perception. These results points to intriguing possibilities for future research. For example, one could causally intervene on dropping behavior with infants who do not yet purposefully drop objects, in order to examine the causal role of motor experience on flexibility in action perception. Such an investigation would also inform current debates regarding the mechanisms underlying action prediction in infancy (e.g., Paulus et al., 2011; Southgate & Csibra, 2009).

It should be noted that the infants in Experiment 2, on average, did not recover attention relative to habituation to any of the height changes in either condition. Thus, while the infants in the narrow container condition looked significantly longer at the higher height change relative to the lower height change, as predicted, this was due to infants looking significantly less at the lower height change relative to habituation. Note that this does not provide evidence that infants failed to notice these changes. In habituation paradigms, infants habituate to everything about the procedure: the room, the seat, the events on the screen, etc. Thus, even though infants did not increase in looking time to either of the height changes, this does not necessarily indicate that they did not notice either of these changes. Additional research would be required to examine this issue in further detail. Importantly though, the difference in looking to the test events in the narrow condition indicates that infants found the higher height change more salient than the lower height change in that condition only.

One limitation of the current research is the reliance on parental report of infants' motor behavior. Parents may have misinterpreted our question about throwing, and thus we may have over or underestimated the degree to which infants attempt throwing and dropping behaviors in their daily life. Future research should devise a way of assessing infants throwing and dropping behaviors in the lab. An additional limitation is that the current findings do not provide evidence that the modulation of attention was actually done in the service of prediction, or that observers were even predicting the outcome of the drop. These results only indicate that attention is increased for prediction-relevant action information. Future research may be able to shed light on whether adults and infants are implicitly evaluating the likelihood of the actor's dropping success. For instance, analysis of observers' eye movements may reveal that for the higher height drop, they less frequently saccade to the container after the object has been released, and look instead to the area adjacent to the container. Thus, this basic finding can be extended and examined further in order to deepen our understanding of the perceptual processes that underlie action prediction.

Previous research has indicated that both adults and 10-month-old infants are biased to attend to hand contact information over spatial trajectory information in human action (Loucks & Baldwin, 2009; Loucks & Sommerville, 2012a). In the current research, adults were highly accurate at detecting spatial changes in drop height, in comparison to the detection of similar spatial action changes to the moving actions (relocating an object) used in Loucks and Baldwin. Although there are additional differences between these two methodologies, the current findings nonetheless suggest that attention to spatial trajectory information may be heightened for dropping actions, as it is generally more relevant for this action than for moving actions. Thus, while the current results showcase flexibility within an action category, there may also be similar flexibility between action categories.

Loucks and Sommerville (2012a) also documented that the hand contact bias develops out of a process of perceptual tuning, between the ages of 4 and 10 months, similar to the tuning that has been identified in other perceptual domains (Cashon & DeNicola, 2011; Kuhl et al., 2006; Lewkowicz & Ghazanfar, 2009; Pascalis, de Haan, & Nelson, 2002; Scott, Pascalis, & Nelson, 2007; Werker & Tees, 1984). If perceptual tuning does occur in action perception, the present results indicate that perception remains relatively flexible following this tuning. On the other hand, perhaps the developmental change that occurs in action perception is not perceptual tuning, but instead reflects the development of an entirely context dependent perceptual system. Additional research is needed to evaluate these two possibilities, in order to further constrain developmental theory in this domain.

While this research has revealed a previously unknown aspect of action perception, it also raises additional new questions. For instance, what guides the selection of perceptual information when action is novel, as is often the case for infants? Are predictive processes the only source of influence on the selection process, or is it also influenced by other processes (e.g., causal learning)? Exactly how flexible is action perception? Is attention during action observation only modulated by extensive experience with particular actions, or can it be altered within an experimental session? Such questions will be the topic of future experiments.

The present findings enrich our understanding of action perception and its development. Given the large amount of perceptual information that could be attended to for even a simple action, selective and flexible sampling of information allows observers to focus attention on what is most relevant. For infants, such adaptive perceptual processes likely help to optimize their learning from others' action. More specifically, they may help infants to predict others' actions with increasing sophistication.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix

Motor Abilities Checklist

Please complete the following questionnaire concerning your child's motor development. Please keep in mind that this scale has been designed for a wide range of ages. Therefore, it is possible that your child can perform **few, some, or many** of the behaviors listed below.

Please check ***yes*** if you have observed the listed behavior, ***mayb****e* if you have not observed the listed behavior yet, but feel it is within your infant's capabilities, or ***no*** if you have not observed the listed behavior and do not feel that your infant could perform it.

	No	**Maybe**	**Yes**
1. Can your child sit alone while playing with a toy?			
2. Can your child maintain a steady sitting position?			
3. Can your child turn from his or her back to his or her stomach?			

	No	**Maybe**	**Yes**
4. Can your child grasp his/her foot with his/her hands?			
5. Does your child make stepping movements?			
6. Can your child attempt to raise his/herself to a sitting position?			
7. Can your child move forward using prewalking methods (e.g. belly crawling, creeping, crawling)?			
8. Can your child support his or her weight momentarily?			
9. Can your child shift his/her weight while standing?			
10. Can your child raise his/herself to a sitting position?			
11. Can your child rotate his/her trunk while sitting alone?			
12. Can your child move from a sitting to a creeping position?			
13. Can your child raise his/herself to a standing position?			
14. Does your child attempt to walk?			
15. Does your child walk sideways holding furniture?			
16. Can your child sit down from a standing position?			
17. Can your child stand on his or her own?			
18. Can your child walk alone?			
19. Can your child walk alone with good coordination?			
20. Can your child throw a ball?			
21. Can your child squat briefly from a standing position?			
22. Can your child walk backwards?			
23. Can your child walk down stairs with help?			
24. Can your child stand on one foot with help?			

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Highlights

“Attending to What Matters: Flexibility in Adults’ and Infants’ Action Perception”

1. Attention during action observation is flexible according to context.
2. Observers modulate attention during action observation according to action prediction.
3. These aspects of attention are observable in adults and young infants.
4. Perceiving others’ aimed dropping is related to individual motor skill at aimed dropping.
5. We compare perceptual performance of adults and infants using highly similar tasks.

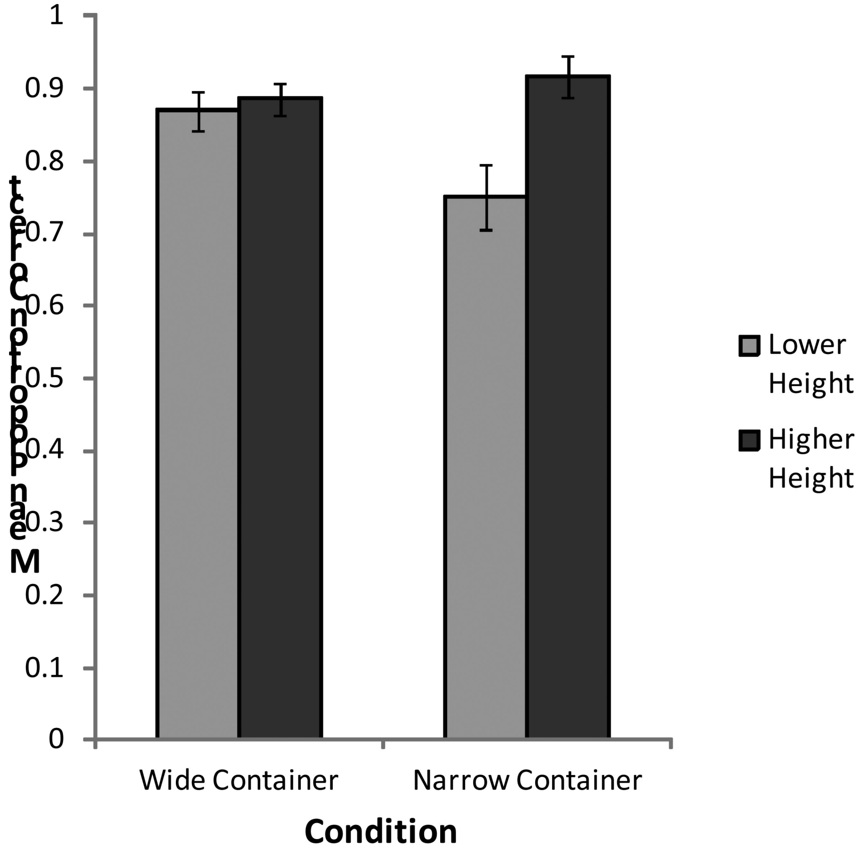

Figure 1.

Mean accuracy rates to detecting lower versus higher height changes as a function of condition (wide vs. narrow container) in the Perception Task of Experiment 1 (adults). Error bars indicate standard error.

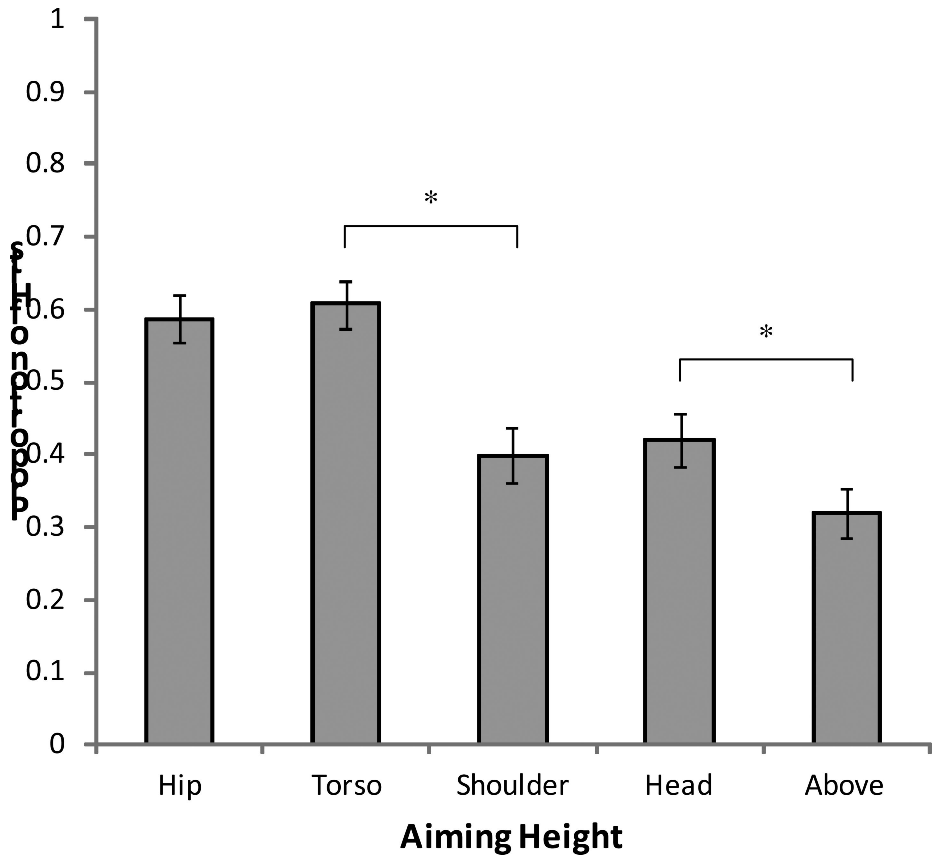

Figure 2.
Mean hit proportions as a function of aiming height in the Dropping Task of Experiment 1 (adults). Bracketed asterisks indicate significant transition points (aiming heights prior to transition point also significant). Error bars indicate standard error.

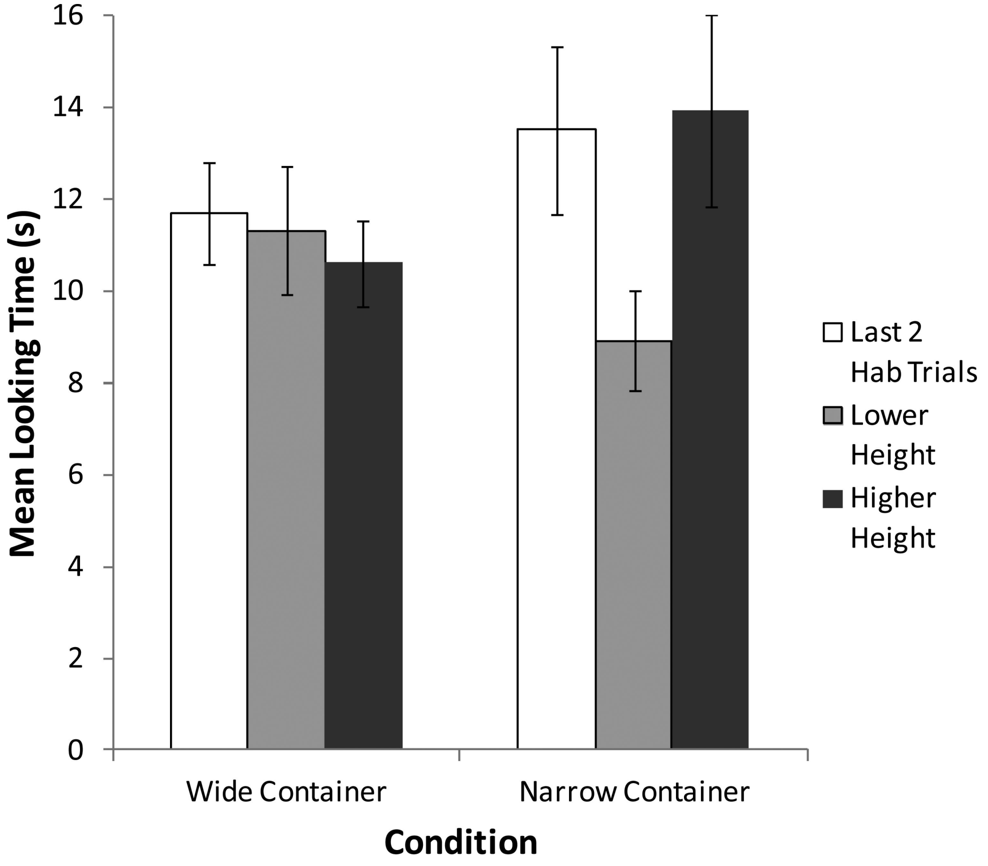

Figure 3.

Mean looking times to the last two habituation trials and the lower and higher height test events as a function of condition (wide vs. narrow container) in Experiment 2 (infants). Error bars indicate standard error.

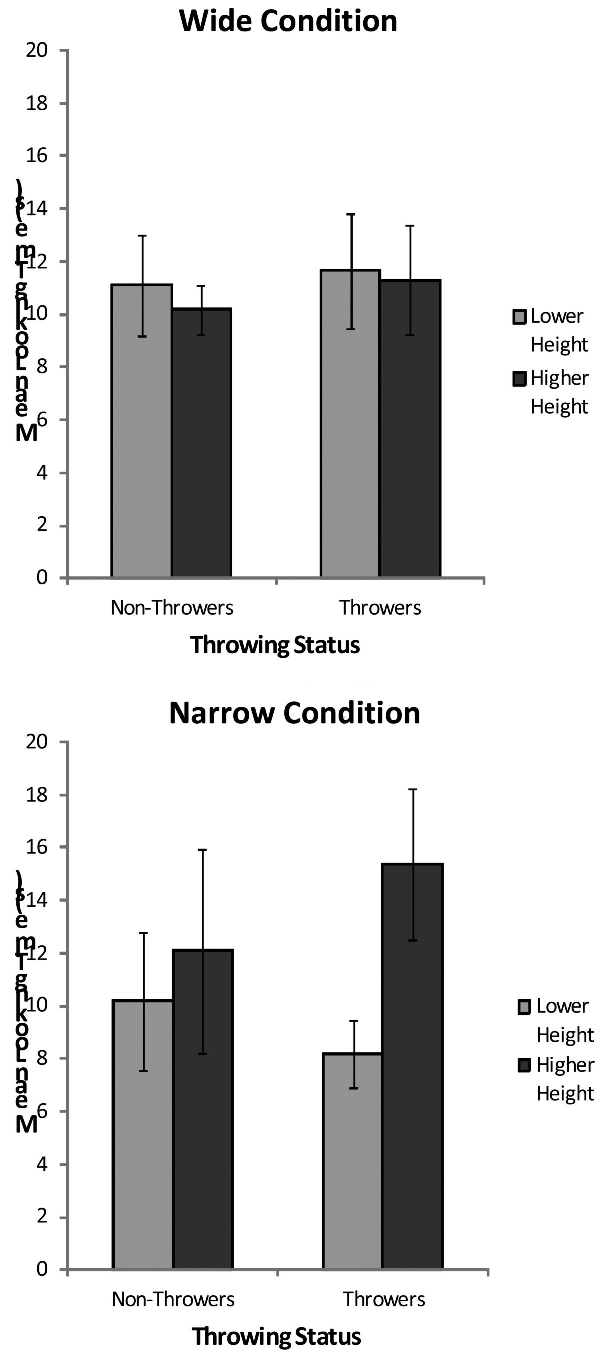

Figure 4.

Mean looking times to the lower versus higher height event as a function of throwing ability (throwers vs. non-throwers) and condition (wide vs. narrow container) in Experiment 2 (infants). Errors bars indicate standard error.