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Developmental Change in Action Perception: Is Motor Experience the Cause?

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Human actions are complex stimuli containing several perceptual dimensions an observer could attend to. Research indicates that attention to the perceptual dimensions of action undergoes a process of perceptual narrowing between 4 and 10 months, during which infants' attention to configural and temporal information in action decreases over time, while attention to hand information is maintained. This research explored whether infants' active experience with grasping is related to perceptual narrowing in action. Across two studies, we tested 6-month-old infants' attention to changes in these action dimensions and also assessed their grasping ability. Infants who were more proficient at grasping showed a pattern more consistent with perceptual narrowing (decreasing attention to configural and temporal information) relative to those less proficient at grasping, especially for attention to configural information. In addition, attention to hand information appears to undergo *U*-shaped development between 4 and 10 months, as 6-month-olds did not recover attention to the hand change. These findings add to a growing body of research showing that infants' motor experience broadly influences their perception of others' action and may follow a complex developmental pathway that diverges from perceptual narrowing over the first year.

Humans are immersed in a world of other people's action. Efficient perception of others' action is not only critical for interacting with others but also fuels our ability to learn from others (Baldwin, 2000; Meltzoff & Williamson, 2010). In this way, processing others' actions is a primary ability in infants' social cognitive development (Baldwin, 2005; Woodward, 2009). However, human actions are not simple stimuli to process: Actions are dynamic, occur rapidly, and contain a great deal of perceptual information.

Despite this complexity, adults readily interpret others' actions as goal-directed—for example, adults construe a reach as directed at a particular object rather than a

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movement through space. This understanding develops early and is observable by 5–6 months of age (Woodward, 1998). However, there has been little research into the perceptual processes that underlie such an analysis of human action. What perceptual information is attended to during action observation, and how does this change over the course of development?

Adults attend to at least three different perceptual dimensions in human action: hand, configural, and temporal information (Loucks, 2011; Loucks & Baldwin, 2009). Hand information is relatively local, detailed-oriented information regarding hand–object interactions, such as the type of grasp used. Configural information is relatively global, spatial–relational information, such as the path along which a body part moves through space. Temporal information is information concerning the speed at which action components are carried out. Adults more readily detect changes to hand information over changes to configural information for a wide variety of actions, even when such changes are objectively smaller (Loucks & Baldwin, 2009). Further research has shown that adults' attention to configural information is flexible depending on the observed action, but never exceeds their attention to hand information (Loucks & Pechey, 2014). Thus, adults often selectively focus on hand information.

How does this selectivity develop? We previously addressed this question by examining 4- and 10-month-old infants' attention to hand, configural, and temporal action information (Loucks & Sommerville, 2012a). Infants were habituated to a standard action, and then shown changes to hand, configural, and temporal information at test. The younger infants attended to all three perceptual dimensions and did not differ in their recovery to each perceptual change. However, 10-month-olds, like adults, selectively attended to changes in hand information, and recovered significantly more to this change in comparison with the other two changes. In other words, infants' attention to configural and temporal information decreased significantly between 4 and 10 months. Thus, action perception appears to undergo a process of perceptual narrowing, akin to similar processes that have been identified in many other domains (Cashon & DeNicola, 2011; Lewkowicz & Ghazanfar, 2009; Scott, Pascalis, & Nelson, 2007).

As Maurer and Werker (2014) discussed, there is a distinction between perceptual narrowing and perceptual tuning, the latter of which pairs decreases in perception for certain stimuli with increases in perception for other stimuli (beyond the maintenance observed in the case of the former). Perceptual tuning occurs in phoneme perception as infants increase in sensitivity to certain native language contrasts after losing sensitivity to non-native contrasts (Narayan, Werker, & Beddor, 2010). In the case of action observation, we have so far only identified narrowing in perception, as no improvement for perception of hand information has been documented; infants begin with relatively broad attention during action perception, but eventually decrease in their attention to configural and temporal information, while maintaining attention on hand information. Another distinction that has been made for narrowing and tuning phenomena concerns the permanence of the process. In phoneme perception, for instance, the loss of perceptual sensitivity is considered fairly permanent, as it is extremely difficult to recover later in life (Pallier, Bosch, & Sebastián-Gallés, 1997). Such is not the case in action perception, as research indicates that attention to configural information varies depending on contextual factors for both adults and infants (Loucks & Sommerville, 2013; Loucks & Pechey, 2016) . Appropriately characterizing what exactly is developing in the case of perceptual narrowing in action observation thus requires more study of the phenomenon. The current research addressed this need in two ways: (1) examining infants' perception of others' action at a transitional age between the large window of 4–10 months and (2) investigating one potential cause of the developmental shift in infants' attention to action dimensions.

In other domains, various types of experience have been shown to play a causal role in perceptual narrowing/tuning. Frequent exposure to particular language contrasts causes perceptual tuning in infants' phoneme perception (Kuhl et al., 2006; Werker & Tees, 1984), and infants' experience hearing individual-level labels paired with faces has been shown to causally shape the course of perceptual narrowing in face perception (Scott & Monesson, 2009). For action perception, what is the relevant experience that drives perceptual narrowing? One possible cause might be infants' own motor experience. Theories have posited that perception and action are intimately linked (Gibson, 1979; Prinz, 1997), and there is much research to indicate that action perception and production share a common underlying processing system (Brass, Bekkering, & Prinz, 2001; Cannon et al., 2016; Daum, Prinz, & Aschersleben, 2011; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Sommerville, Woodward, & Needham, 2005; Southgate, Johnson, El Karoui, & Csibra, 2010). Shared representations between perception and production of action have been shown to influence infants' goal understanding (Sommerville & Woodward, 2005; Sommerville et al., 2005; Woodward, 2009). Prior to 5–6 months of age, infants do not selectively encode the goal of an actors' reach and grasp, nor are they able to perform this action themselves (Woodward, 1998). However, when prereaching 3-month-old infants were given experience with reaching, they subsequently viewed this same action as goal-directed in another's action (Sommerville et al., 2005). Similar findings have been documented with infants' goal understanding for novel tool-use events (Sommerville, Hildebrand, & Crane, 2008).

In the current study, we examined whether motor experience is also related to changes in infants' attention to hand, configural, and temporal information, and in particular whether active experience with grasping was related to perceptual narrowing in action perception. Although even newborn infants display reaching and grasping behaviors, the ability to coordinate these behaviors into an intentional grasp does not emerge until approximately 5 months of age (Gibson, 1988). It is between 5 to 7 months that infants begin to preplan their grasp as their reaches approach objects (von Hofsten & Rönnqvist, 1988) and begin to match their hands to the vertical or horizontal orientation of objects (von Hofsten & Fazel-Zandy, 1984). Models of infant grasping characterize development as increasing prioritization of the grasp relative to the reach in motor planning (Oztop, Bradley, & Arbib, 2004). Perhaps as infants gain experience with grasping themselves, they come to more generally understand that the way in which a hand contacts an object (hand information) is more important for obtaining that object than the way in which the hand gets to the object (configural information) or how quickly or slowly it gets to the object (temporal information). In this way, they may begin to preferentially attend to hand information in *others'* action over time, and attend less to configural and temporal information.

We chose to examine 6-month-old infants, for two reasons: (1) they were in between the ages of 4 and 10 months that we studied previously and (2) they have only recently gained the ability to grasp objects intentionally, and thus there may be significant individual variability in this ability. We assessed infants' attention to hand, configural, and temporal action information and also assessed their grasping abilities. We hypothesized that *increases* in grasping ability would be associated with *decreased* attention to configural and temporal information, but not hand information, as attention to that information is maintained.

STUDY 1

In Study 1, we examined whether individual differences in 6-month-old infants' ability to grasp objects is related to their attention to perceptual dimensions in other people's actions. Infants' grasping proficiency was assessed concurrently with their attention to changes in an actor's moving actions. If grasping abilities are correlated with perceptual narrowing in action perception, then infants who are more proficient with grasping should pay less attention to configural and temporal information relative to those who are less proficient at grasping, but the two groups should not differ in their attention to hand information.

Method

Participants

Participants included 23 6-month-old infants (12 female, M_{age} = 6 months 1 day, range = 5 months 23 days to 6 months 17 days). Participants were recruited from a database of interested families maintained at the University of Washington. An additional 15 infants were tested but excluded from the final sample due to: failure to habituate in the perception task ($N = 11$), excessive fussiness or lack of attention during the perception task ($N = 2$), no attempts to grasp the toys in the action task ($N = 2$), and experimental error ($N = 1$). This sample size was chosen as it was similar to the sample sizes used in the previous work in which perceptual narrowing was identified (Loucks & Sommerville, 2012a). Infants received a small toy as compensation. This study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the Human Subjects Division at the University of Washington where the study was conducted.

Stimuli

Perception task. The stimuli for the perception task were the same four videos used previously by Loucks and Sommerville (2012a). These included a standard video, a hand-change video, a configural change video, and a temporal-change video, all of the same length (7.5 sec). All videos began with an actor seated at a table in front of a toy. In the standard video, the actor grasped the toy with a whole-hand grasp around the outside of the toy, moved it in a straight trajectory across the table, and released it. All of the change videos were nearly identical to the standard, except changed one relevant action property. In the hand-change video, the actor grasped the toy on the inside of the toy cup instead of the outside. In the configural change video, the actor moved the toy in an arcing path instead of a straight trajectory. In the temporal-change video, the actor moved the toy at twice the speed (the reach and withdraw movements were slowed to compensate for the time loss).[1] The actor moved in pace with a metronome for each video, such that the timing of elements remained constant across changes (with the exception of the temporal-change video). The videos looped during playback, giving infants an opportunity to see the changes multiple times per trial.

Action task. Stimuli for the action task included four colored wooden spheres affixed to the ends of wooden dowels. There was a red, yellow, orange, and blue sphere, with diameters of 15, 20, 25, and 30 mm, respectively. A pink plastic teething ring and a multicolored wooden rattle were also used during the breaks between grasping blocks.

Design & Procedure

All infants participated in both the perception and action tasks. Ten infants completed the perception task first, while 13 infants completed the action task first.

Perception task. The perception task was identical to that described in Loucks and Sommerville (2012a,b). Infants were seated in their parent's lap approximately 75 cm from a computer monitor. Parents were asked to remain neutral throughout the task and were also instructed not to look at the screen.

Stimulus presentation and looking time calculations were controlled by Psychtoolbox (Brainard, 1997). An attention-getting stimulus marked the initiation of a trial. Once infants were looking at this stimulus, the video for that trial was presented. Videos played until the infants looked away for two or more seconds, provided they had already looked at the video for a cumulative total of 4 sec. If neither of these criteria were ever met, the video looped a maximum of 10 presentations (80 sec). The next trial began immediately afterward, beginning with the attention-getting stimulus.

During the initial habituation phase, the standard video was shown each trial. Infants remained in the habituation phase until the average looking on the last three consecutive trials was at or below half of the average looking time across the first three trials. Infants could thus view a minimum of 6 and a maximum of 10 habituation trials. The test phase immediately proceeded the habituation phase. In the test phase, each of the change videos was shown twice, in alternating order, with the alternation order fully counterbalanced across infants (six possible orders).

A trained observer coded infants' looking times online, while a second observer recoded infants' looking times offline from video. Trials in which both observers identified the same look away as ending the trial were considered agreements. Agreement was high (84.8%).

Action task. During the action task, infants were seated in their parent's lap in a different room from the perception task. An experimenter sat directly facing infants to present the stimuli. In each trial, the sphere was presented midline, close enough for infants to comfortably reach, and the experimenter tapped the sphere and verbally

[1]It is difficult to objectively scale these three change types. However, Loucks and Baldwin (2009) demonstrated that, contrary to the perceptual abilities of adults, configural changes are typically objectively larger in terms of overall pixel change.

encouraged infants to grasp. If the infant successfully grasped the sphere and began pulling it toward themselves, the experimenter removed the sphere and the trial ended. If the infant attempted to grasp but missed, causing the dowel to be knocked out of position, the experimenter repositioned the dowel. A trial could continue in this manner for a maximum of 30 sec.

Trials were grouped into three blocks of four trials, with each sphere presented once in each block, for a total of 12 trials. In the first block, the order of presentation was small to large: red, yellow, orange, blue. In the second block, the order was yellow, blue, red, orange, and in the last block red, orange, yellow, blue. In between blocks, infants were presented with the teething ring and the wooden rattle and allowed to freely explore these toys, in order to maintain interest in grasping the spheres.

Coding

Infants' grasps were coded offline by an observer. The total number of grasp attempts was coded, and each grasp was coded as either *successful* or *unsuccessful*. A successful grasp was defined as one in which the infant's hand securely gripped the sphere, while an unsuccessful grasp was one in which the infant's hand contacted the sphere but then slipped off. Reaches that did not make contact with the toy were not considered grasps.

From these variables, we calculated infants' grasping *efficiency scores*: the number of successful grasps divided by the total number of grasp attempts. For instance, if an infant grasped unsuccessfully twice before grasping successfully on a trial, the efficiency score for that trial would be 0.33. Efficiency scores on a trial could thus range from 0 (*no successful grasps*) to 1 (*all grasps on a trial successful*). A second coder coded 25% of the videos (n = 6) to determine reliability. Efficiency scores between the two coders were highly similar (M discrepancy = 0.01, SD = 0.03) and correlated highly, $r(5)$ = .982.

Results

A preliminary ANOVA that included gender, task order, and test trial order revealed no significant effects of these variables on infants' recovery to the changes, and thus, these variables were excluded from further analysis.

In order to assess infants' general attention to each of these perceptual dimensions at 6 months, we first assessed their recovery to each type of change by subtracting their mean looking on the last two habituation trials from their mean looking to each change type. Interestingly, as a group, infants did recover significantly to the configural change (M = 1.60 sec, SD = 3.51), $t(22)$ = 2.13, $p < .05$, Cohen's d = 0.63, but did not recover to the hand change (M = 0.86 sec, SD = 2.86), $t(22)$ = 1.44, $p > .16$, or the temporal change (M = 1.00 sec, SD = 3.59), $t(22)$ = 1.38, $p > .18$.

However, our main hypothesis was that infants who were more proficient with grasping would pay less attention to configural and temporal information relative to infants who were less proficient at grasping. We thus created groups of *inefficient graspers* (n = 9) and *efficient graspers* (n = 14) using a median split of efficiency scores. Mean recovery scores to each of the change types for these two groups can be found in Figure 1. A 2 (group) × 3 (change type) mixed ANOVA revealed a significant main effect of group, $F(1,21)$ = 12.49, $p < .002$, partial η^2 = .37, a marginal main effect of test trial, $F(2,42)$ = 2.93, $p < .064$, partial η^2 = .12, and the hypothesized significant

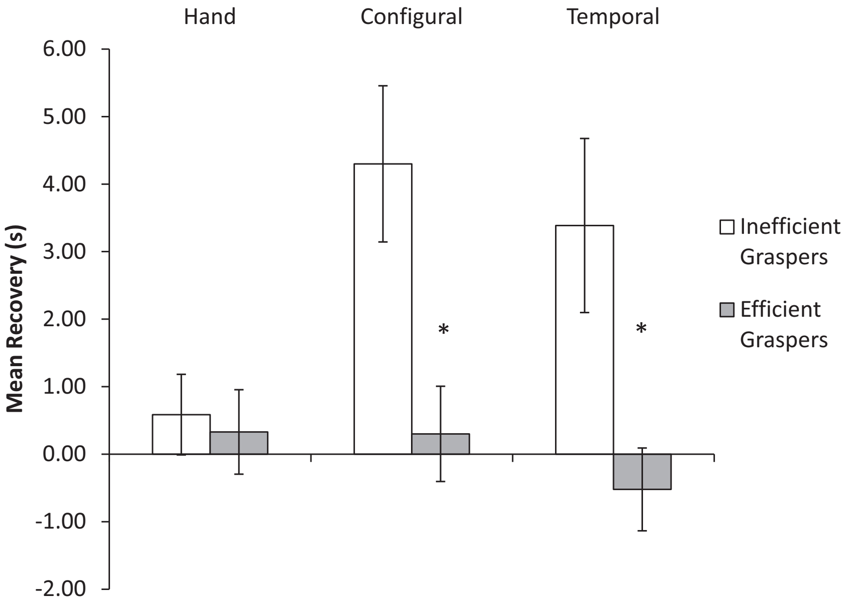

Figure 1 Mean recovery times to each change type for inefficient and efficient graspers in Study 1. Error bars represent standard error, and asterisks indicate significant group differences.

interaction between group and test trial, $F(2,42) = 3.93$, $p < .027$, partial $\eta^2 = .16$. Follow-up planned t-tests indicated that inefficient graspers looked significantly longer than efficient graspers at the configural change, $t(21) = 3.14$, $p < .005$, $d = 1.30$, and the temporal change, $t(21) = 3.06$, $p < .006$, $d = 1.23$, but that the groups did not differ in their looking to the hand change, $t(21) = 0.28$, $p > .78$.

We further investigated whether these two groups differed in their recovery from habituation. Inefficient graspers recovered significantly to the configural change, $t(8) = 3.72$, $p < .006$, and the temporal change, $t(8) = 2.63$, $p < .030$, but did not recover to the hand change, $t(8) = 0.98$, $p < .36$. In contrast, efficient graspers did not recover to any of the change types, all p's $> .41$.

We also conducted an analysis to examine whether significant recovery occurred relative to habituation for the first test trial shown across the six orders—a stringent test of whether infants could discriminate the three change types. In this analysis, $n = 7$ infants were shown a hand change first, $n = 8$ were shown a configural change first, and $n = 8$ in order 3 were shown a temporal change first. Because of the low power of these tests, we also considered effect size in our interpretation of the results. Although not significant, only the configural change ($M = 1.58$) demonstrated recovery of a moderate effect size, $t(7) = 1.58$, $p > .16$, $d = 0.56$, while the hand change ($M = 0.72$) and the temporal change ($M = 0.05$) were not significant and demonstrated small effect sizes, $t(6) = 0.72$, $p > .49$, $d = 0.27$, and $t(7) = 0.05$, $p > .94$, $d = 0.03$.

Discussion

The results of Study 1 supported portions of our hypothesis that grasping experience is related to the process of perceptual narrowing in action. The developmental pattern that Loucks and Sommerville (2012a,b) identified was that 4-month-old infants attend equally to hand, configural, and temporal information, but that 10-month-old infants selectively attend to hand information. In the current study, 6-month-olds who were more proficient with grasping attended significantly less to configural and temporal information, similar to their 10-month-old counterparts, whereas those less proficient attended more to these dimensions, similar to their 4-month-old counterparts. Importantly, as predicted, proficiency was not related to attention to hand information. One possibility is that infants' experience with grasping leads them to recognize that hand contact information is typically a more important variable in the success or failure of a grasp in comparison with configural and temporal information, which have less of an impact and can vary more freely in regard to success.

However, one finding that is at odds with a perceptual narrowing interpretation is that infants in neither group paid significant attention to the hand change. We were surprised by this result, as hand information is salient for both 4- and 10-month-olds, and perceptual narrowing in other domains is characterized by some maintenance of discriminability in relation to identified decreases. On the surface, this appears to be an indication of *U*-shaped development in human action perception for this action dimension. Alternatively, perhaps infants at this age do attend to hand information, but our task was not sensitive enough to reveal this aspect of 6-month-olds' attention. One possibility is that infants at this age need to be more engaged with the events in order to fully attend to hand information.

Thus, in Study 2 we altered the perception task such that live events were shown instead of video events. Research on adult and infant motor activation during action observation has indicated that activation is less pronounced when observers view televised action compared to live action (Järveläinen, Schürmann, Avikainen, & Hari, 2001; Shimada & Hiraki, 2006). This may be reflective of the broader video deficit that has been documented in which infants display poorer performance when video stimuli are used compared to live action (Anderson & Pempek, 2005). Such deficits have been documented for imitation of action (Barr & Hayne, 1999), but do not appear to be present in 6-month-olds (Barr, Muentener, & Garcia, 2007). Thus, it seemed plausible that using live events would allow infants to be more engaged with the stimuli and/or process the stimuli more deeply. With deeper processing, perhaps infants will demonstrate increased attention to hand information.

Study 2 also provided an opportunity to replicate the findings of Study 1 with a larger sample size. In designing this study, we also altered the action task to make it more challenging for infants, so we could more finely discriminate efficient from inefficient graspers. To do so, we used wooden balls hung from the ends of the wooden dowels rather than being directly affixed to the dowels as in Study 1. In this case, the infant must carefully control the deceleration of their reach as the hand approaches the object to successfully grasp, else the ball will be knocked out of place. Thus, with both tasks altered, we could assess the generalizability of these initial findings.

STUDY 2

Participants

Participants included 31 6-month-old infants (13 female, M_{age} = 6 months 14 days, range = 6 months 2 days to 6 months 29 days). Participants were recruited from a database of interested families maintained at the University of Regina. An additional 17 infants were tested but excluded from the final sample due to: failure to habituate in the perception task (N = 5), excessive fussiness or lack of attention during the perception task (N = 8), no attempts to grasp the toys in the action task (N = 2), and experimental error (N = 2). Parents were compensated with $10, and infants were compensated with a small toy. As in Study 1, this study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the Research Ethics Board the University of Regina where the study was conducted.

Stimuli

Perception task

Stimuli for the perception task included a small pink toy stacking cup (9.5 cm in diameter). All actors (3) also wore the same blue shirt and were all female.

Action task

Stimuli for the action task included four colored wooden spheres affixed to the ends of wooden dowels. There was a red, yellow, orange, and blue sphere, with diameters of 15, 20, 25, and 30 mm, respectively.

Design & Procedure

All participants participated in the perception task followed by the action task. We initially counterbalanced task order; however, a high number of infants became too fussy during the perception task when they completed the action task first (52% of the sample). Thus, we discontinued this order and only added new infants to the perception task first order.[2]

Perception task

During the perception task, infants sat in their parent's lap approximately 100 cm in front of a display. The display contained a table (60 × 75 cm) that supported a toy cup on the right-hand side and a female actor seated behind the table. A brown curtain attached to the ceiling could be shifted by the experimenter to block the infants' view of the display between trials. A camera affixed to the underside of the table was used to record infants' looking and was hidden behind a black curtain affixed to the table which draped to the floor.

A schematic of the events shown in the perception task can be found in Figure 2. During the initial habituation phase, infants were shown a habituation event in which the actor said, "Hi! Look," then reached toward and grasped the cup with a precision grasp inside of the cup, and moved it in a straight trajectory across the table to the

[2]Because task order has no significant effects on performance on either task in Study 1, we were less concerned about the loss of this variable in Study 2.

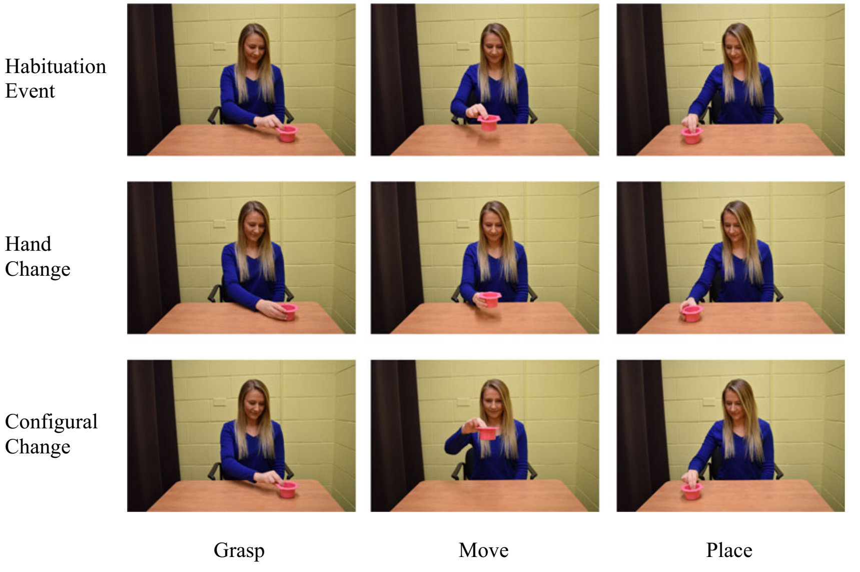

Figure 2 The habituation event and the hand and configural test events shown in Study 2.

left-hand side. The actor then held this pose until the end of the trial. Start and end locations of the object were marked with scotch tape. Actors moved in pace with a metronome played through a Bluetooth earbud headphone, such that every trial involved the same timing of elements: "Hi" (0 sec), "Look" (2 sec) reach and grasp (4 sec), move (5 sec), "Wow", and cup at final position (7 sec). Infant looking was coded online starting from the point at which the actor said "Wow" and ending when the infants looked away for two consecutive seconds. The curtain was then pulled in front of the display, the display was reset, and the curtain was raised to being the next trial. Habituation trials were shown until the infant's looking on the last three consecutive trials was 50% or less of what it had been on the first 3 trials, or until 12 trials, whichever came first. Thus, infants viewed a minimum of 6 and a maximum of 12 habituation trials.

The test phase immediately followed the habituation phase and followed the identical trial structure. Test events were identical to the habituation event except as otherwise noted. In the hand-change event, the actor grasped the outside of the cup instead of the inside with a whole-hand grasp. In the configural change event, the actor moved the cup in a parabolic trajectory (~30 cm instead of ~5 cm at maximum height). In the temporal-change event, the actor completed the reach event in 2 sec (instead of 1 sec) and the move event in 1 sec (instead of 2 sec). Infants viewed two trials of each test event, in alternating order. Test trial order was counterbalanced across infants in a Latin square design (three possible orders: HCT, CTH, and THC).

A trained observer coded infants' looking times online, while a second observer recoded infants' looking times offline from video. Trials in which both observers identified the same look away as ending the trial were considered agreements. Agreement was high (92.5%).

Action task

As in Study 1, the action task was conducted in a different room from the perception task, with infants seated in their parent's lap across from the experimenter. In each trial, the sphere was presented midline, close enough for infants to comfortably reach, and the experimenter verbally encouraged infants to grasp. If the infant successfully grasped the sphere and began pulling it toward themselves, the experimenter removed the sphere and the trial ended. If during a failed attempt the sphere was knocked out of place, swinging back and forth, the experimenter repositioned the sphere. A trial could continue in this manner for a maximum of 30 sec. Each sphere was presented three times in a fixed order, from largest to smallest, across three blocks of trials, resulting in 12 total trials.

Coding

Successful and unsuccessful grasps as well as efficiency scores were coded in the same manner as in Study 1. A second coder coded 25% of the videos ($n = 8$) to determine reliability. Efficiency scores between the two coders were once again highly similar (M discrepancy = 0.02, $SD = 0.06$) and correlated highly, $r(7) = .933$.

Results

A preliminary ANOVA that included gender and test trial order revealed a marginal interaction between change type and order on infants' recovery scores, $F(4,38) = 2.12$, $p < .097$, partial $\eta^2 = .18$. Thus, we included this variable in certain analyses reported below. However, there were no significant effects of gender on recovery, and so, this variable was excluded from further analysis.

In order to determine whether live action altered infants' general attention to each of the action dimensions, we again examined infants' recovery to each change type as a single group. The pattern of findings was only slightly different for live action compared to video: as a group, infants did not recover to the hand change ($M = -0.25$ sec, $SD = 2.98$), $t(29) = 0.46$, $p > .64$, the configural change ($M = -0.74$ sec, $SD = 3.25$), $t(29) = 1.27$, $p > .21$, or the temporal change ($M = 0.37$ sec, $SD = 2.90$), $t(29) = 0.70$, $p > .48$.

Our main hypothesis again centered upon whether relative differences in grasping proficiency would be associated with relative differences in attention to configural and temporal information. We thus once again created groups of inefficient graspers ($n = 16$) and efficient graspers ($n = 15$) based on a median split of efficiency scores. A 2 (group) × 3 (order) × 3 (change type) mixed ANOVA revealed a significant main effect of order, $F(2,25) = 4.08$, $p < .029$, partial $\eta^2 = .25$. Post hoc Tukey tests indicated that infants in order 3 ($M = -1.58$, $SD = 0.62$) recovered marginally less to the events than infants in order 1 ($M = 0.61$, $SD = 0.62$), $p < .076$, and order 2 ($M = 0.51$, $SD = 0.58$), $p < .072$. There was also a marginal interaction between change type and order, $F(4,50) = 2.49$, $p < .055$, partial $\eta^2 = .17$, and the hypothesized significant interaction between change type and group, $F(2,50) = 4.12$, $p < .022$, partial $\eta^2 = .14$. Unlike in Study 1, there was no significant main effect of change type, $F(2,50) = 1.03$, $p > .37$, or group, $F(1,25) = 1.28$, $p > .27$, and there was no significant three-way interaction between the variables, $F(4,50) = 1.50$, $p > .22$.

We first explored the hypothesized interaction between change type and group. Mean recovery to each of the change types for each group can be found in Figure 3. Planned follow-up *t*-tests indicated that inefficient graspers recovered significantly more to the configural change than did the efficient graspers, $t(29) = 2.32$, $p < .028$, $d = 0.84$. In contrast to Study 1 and our hypothesis, these groups did not differ in their recovery to the temporal change, $t(29) = 0.97$, $p > .34$. However, as hypothesized, the groups also did not differ in their recovery to the hand change, $t(29) = 0.18$, $p > .86$. We also analyzed recovery from habituation separately for each group. In contrast to Study 1, inefficient graspers did not recover to any of the change types, all *p*'s > .41. Interestingly, efficient graspers showed significant *continued habituation* to the configural change (i.e., less looking during test than habituation), $t(14) = 3.11$, $p < .008$, $d = 1.01$, but no recovery to the hand change $t(14) = 0.35$, $p > .73$, or the temporal change, $t(14) = 1.19$, $p > .26$.

To examine the interaction between order and change type, we conducted one-way ANOVAs for order on recovery scores separately for each change type. Mean recovery to each change type for each order can be found in Figure 4. There was a significant effect of order for the hand change, $F(2,28) = 6.78$, $p < .004$, $\eta^2 = .33$, and a marginal effect for the temporal change, $F(2,28) = 3.02$, $p < .065$, $\eta^2 = .18$, but no effect for the configural change, $F(2,28) = 0.43$, $p > .66$. Post hoc Tukey tests revealed that for the hand change, infants recovered marginally more when it was the first change shown (order 1) than when it was the third change shown (order 2), $p < .078$, and significantly more than when was the second change shown (order 3), $p < .003$. For the temporal change, there was no significant difference in recovery when it was the third change shown (order 1) and the second change shown (order 2), but recovery in order 2 was marginally higher than when it was the first change shown (order 3), $p < .054$.

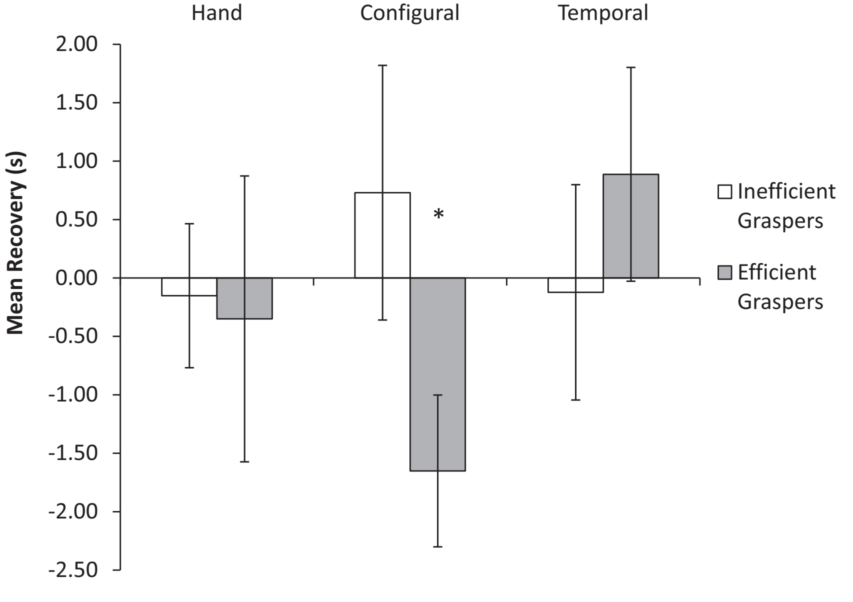

Figure 3 Mean recovery times to each change type for inefficient and efficient graspers in Study 2. Error bars represent standard error. The asterisk indicates a significant group difference.

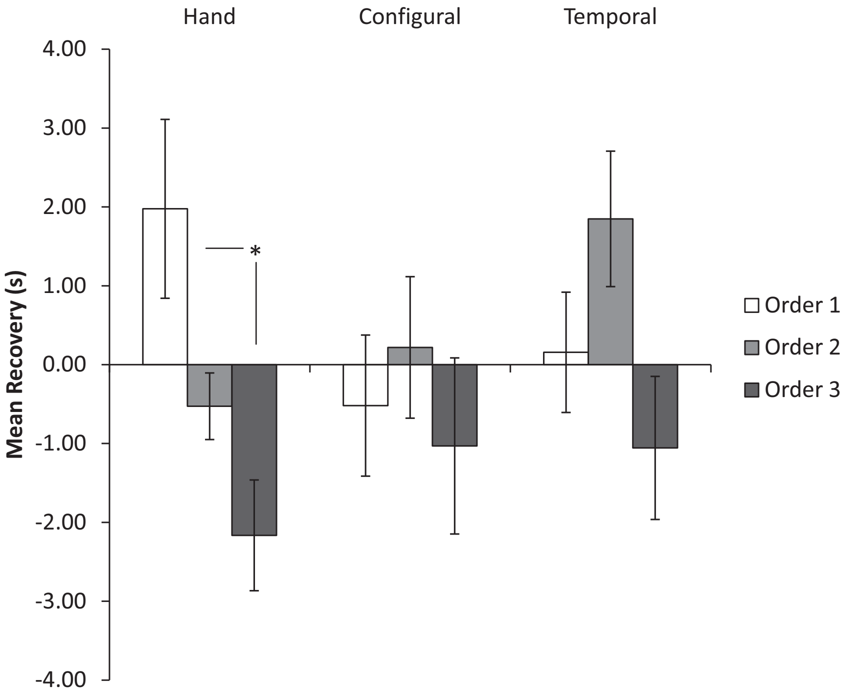

Figure 4 Mean recovery times for each change type by order in Study 2. Error bars represent standard error. The asterisk indicates a significant difference.

Finally, we also conducted an analysis of recovery from habituation for the first test trial shown across the orders. In this analysis, n = 10 infants in order 1 were shown a hand change first, n = 11 in order 2 were shown a configural change first, and n = 10 in order 3 were shown a temporal change first. Because of the low power of these tests, we again considered effect size in interpreting these results. Only the hand change demonstrated marginal recovery with a moderate effect size, $t(9) = 1.98$, $p < .079$, $d = 0.63$, while the configural and the temporal change demonstrated no recovery with small effect sizes, $t(10) = 0.91$, $p > .39$, $d = 0.27$, and $t(9) = -0.15$, $p > .88$, $d = 0.24$.

Discussion

Despite differences in habituation and action methodologies, we again observed elements of the hypothesized relationship between grasping proficiency and perceptual narrowing. Infants who were more adept at grasping in their own behavior paid less attention to configural information in action, like 10-month-old infants and adults (Loucks & Pechey, 2016; Loucks & Sommerville, 2012a,b). However, there was no similar relationship between grasping efficiency and attention to the temporal change, as was observed in Study 1. We believe that differences in stimulus presentation likely account for this discrepancy, but the precise mechanism is unclear. Infants' interest in both the temporal change and the hand change varied by order, suggesting that there may have been complex effects of context on infants' attention. In this study, infants only received one presentation of the temporal change on each test trial, whereas infants had multiple opportunities to view this change per trial in Study 1. It is also possible that an increase in the visual angle of the action in Study 2 altered the salience of this information or that live action itself alters the salience of this information. In either case, it remains possible that attention to temporal information is related motor abilities (as indicated by Study 1) but that our methodology precluded the observation of this relation in Study 2. Further research on attention to temporal information in infants and adults can help to clarify the nature of these ambiguous findings (underway in our laboratory).

We also replicated the relatively low attention to hand information observed in Study 1. Live action did increase the salience of this information to some extent: as a group, infants showed recovery to only this change, and not the configural or temporal change, when it was the first change presented. This is a notable change from Study 1, in which the configural change was the only change infants recovered to on the first test trial. But we have no evidence that infants can robustly notice this change with different test sequences at 6 months of age. This lends further support to the idea that attention to hand information appears to undergo *U*-shaped development between the period of 4–10 months. We will discuss the implications of this finding in the general discussion.

GENERAL DISCUSSION

When infants observe the actions of others, there are many perceptual dimensions they could attend to and encode. Loucks and Sommerville (2012a) found that young infants initially attend broadly to multiple perceptual dimensions of action and attend equally to hand, configural, and temporal action information, but by 10 months of age selectively attend to hand information over the other two dimensions, like adults do (Loucks & Baldwin, 2009). The present findings indicate that changes in infants' emerging grasping abilities are linked to this process of perceptual change. As infants become more efficient in their execution of intentional grasps, they also attend less to configural information, and somewhat less to temporal information, like older infants and adults. Thus, the present research has identified a candidate causal factor in developmental change in action perception. In addition, the present research has also uncovered a curious developmental trajectory for attention to hand information, which we had previously assumed was maintained between 4 and 10 months. Instead, considering the findings from multiple studies, it appears to follow a *U*-shaped trajectory, with relatively high attention at 4 months, low attention at 6 months, and returning to high attention by 10 months. For this reason, the term perceptual narrowing does not accurately reflect the pattern of data we have observed, despite some overlap in the phenomena and the data.

Overall, the current results are consonant with other theoretical perspectives that posit a common underlying representational system for action production and perception (Prinz, 1997). In infancy, research has documented links between infants' active motor experience and goal understanding (Sommerville & Woodward, 2005; Sommerville et al., 2005; Woodward & Guajardo, 2002), tool-use understanding (Sommerville et al., 2008), and action anticipation (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Kanakogi & Itakura, 2011; Rosander & von Hofsten, 2011). Here, we have documented that active experience is also related to developmental change in infants' attention to perceptual dimensions in others' action.

From this common coding perspective, attention to hand information in action observation may be maintained (in the long run) because it is a critical aspect of infants' own motor behavior. As infants are motivated to obtain objects in their environment, they must come to recognize that successful object capture is largely dependent on the way in which their hand contacts an object. As this information becomes more prominent in their own motor representations at this early stage of grasping, it may remain prominent in their perception of others' actions. Configural and temporal control in the infants' own actions, while still a critical component of action production more generally, may be more variable in their importance with respect to object capture. Thus, mirroring the early experiences that occur with the onset of grasping, infants' attention to these two sources of information in others' action also undergoes significant reduction (though perception of these dimensions is not entirely lost).

To the extent that infants are in fact utilizing their motor system to perceive others' actions, these perceptual changes may reflect early developments in this common coding system. Common coding is thought to aid in predicting others' action (Blakemore & Frith, 2005). As infants' fine motor abilities continue to develop, they may come to recognize that grasps have functional consequences for possible future actions they can perform with an object. Attention to hand information in others can thus become useful in order to evaluate functional consequences in order to constrain prediction. We have previously shown that 10-month-olds are sensitive to such functional consequences in others' action, and this sensitivity is tied to individual differences in grasping capabilities (Loucks & Sommerville, 2012b). Filippi and Woodward (2016) also recently demonstrated that attention to hand information is relevant for predictive tracking of action, and similarly demonstrated a link between infants' action capabilities and their predictive tracking of others' action from hand information. While the current results do not demonstrate such predictive abilities in 6-month-old infants, they nonetheless seem to be preparing infants for the development of future-oriented action processing capabilities.

In addition, the common coding perspective may help to explain the puzzling *U*-shaped trajectory for hand information. In other cases of *U*-shaped development, disruption to neural circuitry due to significant growth or reorganization has been implicated as the cause of reduced performance (e.g., Morton & Johnson, 1991). Within the motor system, Chen, Metcalfe, Jeka, and Clark (2007) documented that the onset of walking coincides with a temporary disruption (*U*-shaped pattern) in the postural sway system. Motor achievements have also been implicated in the disruption of perceptual systems as well: Cashon, Ha, Allen, and Barna (2013) demonstrated that *U*-shaped development in infants' holistic face processing is correlated with independent sitting ability. In the case of grasping and action observation, it may be that the neural grasping circuit is undergoing significant development at this age, which results in a temporary reduction in attention to hand information in processing others' action, while the circuit is either overloaded or undergoing reorganization. Much additional research is needed to evaluate this intriguing possibility, including replication of this effect across different types of actions.

The mature state of the action processing system is one which selectively attends to hand information, and is potentially more sensitive to perceiving changes in hand information, than other perceptual changes. Adults are finely sensitive to what other people's hands are doing, even when no clear goal is present (i.e., action miming in Loucks & Pechey, 2016), and by 10 months, infants discriminate changes in other people's grasps that have no clear impact on the execution of a goal (Loucks & Sommerville, 2012b). Thus, further research is needed to discover when attention to hand information returns to prior levels, and whether or not its return is concomitant with enhancement or attunement in the perception of hand information. From an information processing perspective, it seems plausible that a decrease in processing of configural and temporal information would have to precede an enhancement in the processing of hand information, as this would free up resources for more intensive processing (again, in the long run). In the phoneme perception literature, there are no studies that have directly delineated when non-native processing is lost relative to when native processing is enhanced in the same sample, and likewise in the face perception literature. A more detailed investigation of timing in all of these domains might reveal a complex interplay between decreasing and increasing abilities.

The notable similarity between perceptual narrowing and the current data is the reduction in sensitivity to configural information, and to some extent temporal information. This reduction in sensitivity appears to be occurring by 6 months, as infants gain experience coordinating grasps with reaches. This change occurs earlier than similar reductions in sensitivity that occur in speech, face, music, and intersensory perception, between approximately 9 and 12 months (Hannon & Trehub, 2005; Lewkowicz & Ghazanfar, 2006; Pascalis, de Haan, & Nelson, 2002; Werker & Tees, 1984), but later than similar changes that occur in primary visual perception at 4 months of age (Dobkins, 2009). Presumably, reduced sensitivity in all domains is instantiated in the retraction of underused synaptic connections (Huttenlocher, 1990), with differences in timing reflecting the maturation of the underlying neuronal systems responsible for the phenomena. It is not yet clear what precise neuronal mechanisms are responsible for changes in infants' action perception. If such changes reflect developments in the reach and grasp circuit (common coding theory), they may involve synaptic pruning in parietofrontal cortex, or projections from occipital cortex into parietofrontal cortex (Karl & Whishaw, 2014). On the other hand, they may involve pruning in regions that underlie a more visual analysis of action, like the superior temporal sulcus, which are responsible for biological motion perception (Grossman & Blake, 2001; Thompson & Parasuraman, 2012). Because action observation relies on multiple circuits, a simple explanation from a neural developmental perspective is unlikely. In any case, these changes in action perception occur alongside additional notable achievements in infants' action processing at 6 months (Daum et al., 2011; Kanakogi & Itakura, 2011; Woodward, 1998), indicating that significant development is occurring in this domain at this age.

A critical next step for this line of research will be to directly investigate the causal pathway of perceptual change in action observation. Motor experience may be the causal factor, but there exist other possibilities. For instance, the emergence of goal understanding for reaching and grasping actions also develops between 5 and 6 months (Woodward, 1998), and motor experience has been shown to play a causal role in the development of this understanding (Sommerville et al., 2005). Perhaps goal understanding and perceptual change are both the sequela of grasping experience, or perhaps goal understanding fuels perceptual change by way of grasping experience. Future research is needed to explore these distinct possibilities.

In sum, the present findings are the first to identify a potential causal mechanism behind changes in infants' attention to perceptual information during online action observation. Given the myriad perceptual dimensions that could be attended to and encoded for even a simple action, infants learn to selectively sample certain dimensions over others. These findings suggest that infants may be using their own motor experience to guide the selection of perceptual information contained in the dynamic actions of others, which follows a complex developmental trajectory over the first year.

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