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PAPER

Dynamic pointing triggers shifts of visual attention in young infants

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Abstract

Pointing, like eye gaze, is a deictic gesture that can be used to orient the attention of another person towards an object or an event. Previous research suggests that infants first begin to follow a pointing gesture between 10 and 13 months of age. We investigated whether sensitivity to pointing could be seen at younger ages employing a technique recently used to show early sensitivity to perceived eye gaze. Three experiments were conducted with 4.5- and 6.5-month-old infants. Our first goal was to examine whether these infants could show a systematic response to pointing by shifting their visual attention in the direction of a pointing gesture when we eliminated the difficulty of disengaging fixation from a pointing hand. The results from Experiments 1 and 2 suggest that a dynamic, but not a static, pointing gesture triggers shifts of visual attention in infants as young as 4.5 months of age. Our second goal was to clarify whether this response was based on sensitivity to the directional posture of the pointing hand, the motion of the pointing hand, or both. The results from Experiment 3 suggest that the direction of motion is necessary but not sufficient to orient infants' attention toward a distal target. Infants shifted their attention in the direction of the pointing finger, but only when the hand was moving in the same direction. These results suggest that infants are prepared to orient to the distal referent of a pointing gesture which likely contributes to their learning the communicative function of pointing.

Introduction

The understanding of deictic gestures is a fundamental aspect of social communication. It is an integral part of joint attention to people, objects, and events (Bruner, 1975; Tomasello, Carpenter & Liszkowski, 2007) involving the 'simultaneous engagement of two or more individuals in mental focus on one and the same external thing' (Baldwin, 1995, p. 132). Based on this definition, shared attention is an important prerequisite for effective communication. It is thus advantageous to diagnose when infants are first capable of 'naïve' deictic gesture following (cf. Frischen, Bayliss & Tipper, 2007).

Until recently, it was believed that the ability of following deictic gestures first emerged between the ages of 10 to 13 months, both for following eye gaze (Butterworth & Jarrett, 1991; Corkum & Moore, 1995; Scaife & Bruner, 1975) and pointing gestures (Desrochers, Morissette & Ricard, 1995; Carpenter, Nagell & Tomasello, 1998; Leung & Rheingold, 1981; Tomasello *et al*., 2007). The findings from a pivotal study by Hood, Willen and Driver (1998), however, changed our understanding of the developmental trajectory of infants' responsiveness to perceived eye gaze, demonstrating that they follow eye gaze at much younger ages, and perhaps, even from birth (Farroni, Massaccesi, Pividori, Simion & Johnson, 2004a). Although it is conceivable that young infants are also responsive to pointing gestures, there is currently no evidence to support this conjecture. The goal of the current study is to adapt the paradigm of Hood and colleagues (1998) to investigate whether young infants will shift their gaze in the direction of a pointing gesture.

One problem in studying young infants orienting to deictic gestures is that they have difficulty disengaging from a central salient stimulus in order to orient to a peripheral stimulus (Hood, 1995). In the case of testing whether infants follow the directional orientation of the eyes, this means that infants will continue to focus attention on the face rather than looking in the direction specified by the gaze of the eyes (Hood *et al*., 1998). To address this issue, Hood and colleagues (1998) adapted the method developed by Posner (1980) for studying spatial orienting in which visual attention is cued in one direction before a probe stimulus appears either to the left or to the right of the cueing stimulus. Subjects respond to the appearance of the probe stimulus congruent with the cueing stimulus faster than they respond to the probe stimulus that is incongruent with the cueing stimulus. In the paradigm adapted by Hood and colleagues, infants were initially shown a centrally

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presented digitized adult face in which the eyes moved to the right or left. Simultaneous with the presentation of the probe stimulus, the face disappeared so there was no need for infants to disengage attention before looking toward the probe. The results showed that infants as young as 3 months of age looked more quickly to targets appearing in the direction cued by eye gaze, indicating some level of sensitivity to the referential nature of gaze.

Farroni and colleagues (2000) replicated the finding of Hood and colleagues (1998) and further showed that motion of the pupils is essential for this effect. When there was no apparent movement of the pupils and directional gaze was presented statically, there was no evidence that 4-month-old infants followed the gaze shift. These data thus reveal that motion is an important cue for infants, but it becomes less important during development (Farroni, Johnson, Brockbank & Simion, 2000). For example, while young infants' gaze-following depends on seeing the adult's head movements rather than their final head pose, older infants can use a static pose to infer direction of attention (Moore, Angelopoulos & Bennett, 1997). In specifying further crucial features that orient infants' attention, a common finding appears to be that it is motion in biological stimuli that is necessary to elicit the response (Johnson, Slaughter & Care, 1998; Farroni, Johnson & Csibra, 2004b; Striano & Reid, 2006).

From the perspective of the (proto-)function of a deictic gesture, such as eye gaze and pointing, it is significant to note that the attentional cue in the Hood *et al.* study was not in the same location as the probe stimulus, but simply 'pointed' to that location. Thus, faster responding to the spatially congruent cue required that infants understand that the change in gaze direction specified the location of the distal probe.

Our research was motivated by the thesis that pointing – similar to eye gaze – is a deictic gesture used to orient the attention of another person towards an object or an event (Butterworth, 2003). It was recently reported that 8-month-old infants show greater electroencephalographic (EEG) activation for targets that are congruent with a pointing gesture than are incongruent with the gesture (Gredebäck, Melinder & Daum, 2010). The authors interpret their findings as suggesting that infants begin to process the functional aspects of pointing before they actually start to point or follow others' pointing gestures.

Motivated by the studies showing that 4-month-old infants are sensitive to the congruency between somebody's eye gaze and the location of a target (Farroni *et al.*, 2000, 2004a), our aim was to investigate further the early stages of referential understanding of a pointing gesture to gain more insight into what functional aspects contribute to the communicative situation. We therefore asked whether sensitivity towards functional aspects of a pointing gesture can be observed in 4-month-olds. We focused on a form of 'referential expectation' (Gliga & Csibra, 2009, p. 352) and tested whether infants look to the location of an object or event cued by a pointing gesture. This ability would support recent research about early pointing serving a communicative and declarative function (e.g. Franco & Butterworth, 1996; Liszkowski, 2005) rather than only a requesting or imperative function (e.g. Vygotsky, 1978; Camaioni, 1993; Moore & D'Entremont, 2001).

Experiment 1

In this experiment, we tested whether 4.5- and 6.5-month-old infants orient in the direction of a pointing finger on a human hand.

Method

Subjects

Ten 4.5- (M = 128 days, SD = 15.6) and ten 6.5-month-old (M = 195 days, SD = 19.6) healthy, full-term infants were tested. Most infants were Caucasian, middle-class, and lived in Chicago or its surroundings. Parents gave written informed consent before testing begun.

Stimuli

A computer-animated stimulus movie was created with Macromedia Director and assembled with scripts so that it could be interactively controlled when played. The movie consisted of 16 events and was played twice, so a total of 32 events were presented to each infant. Each event constituted a single trial. The trials were randomized in a discrete manner, i.e. four movies with different presentation orders were created.

At the beginning of each stimulus event, a human hand appeared on the screen with fingers oriented upwards. We chose a human hand in isolation to make the stimulus comparable to the stimuli presented by Hood and his colleagues (1998). Our concern was that other presentations with a fully specified person would have probably distracted the infants from perceiving the hand. The fingers of the presented hand waved back and forth (see Figure 1) and were accompanied by a voice saying 'look baby, look!' as an ostensive cue (Senju & Csibra, 2008) to get the baby's attention; it continued until the infant fixated the hand. Once the infant oriented toward the hand, a canonical pointing gesture appeared in the center of the screen (see Figure 2), moving slightly back-and-forth (moving to the side approximately 2 cm and coming back to the center, i.e. the starting position). On half of the trials, the hand (subtending a visual angle of 15.9° (width) × 14.9° (height)) pointed right and on the other half of the trials the hand pointed left. This segment lasted 1000 ms. Subsequently, the hand disappeared and was replaced by an image of a toy (an Elmo puppet [6.4° height, 4.2° width] or a clown [6.4° height, 4.8° width]) that appeared at a distance of 15 cm from the tip of the finger (7.75% of

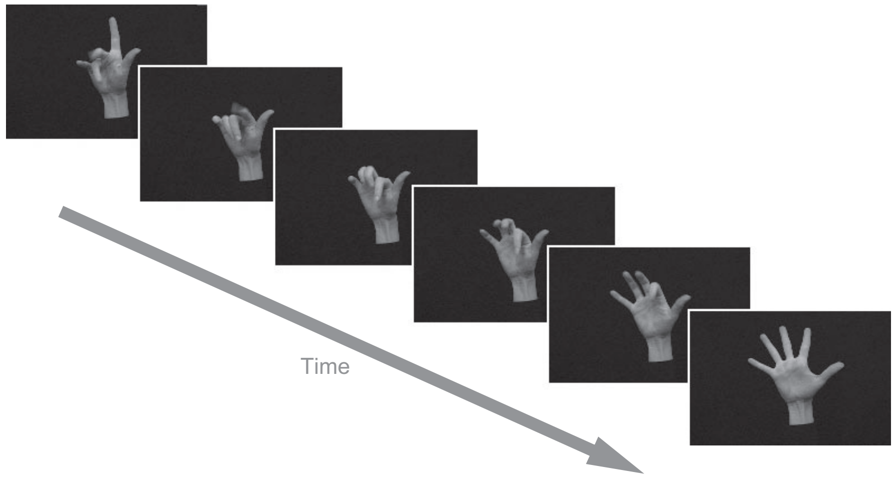


Figure 1 *A sequence of static frames from the movie showing the fingers waving to attract the infant's attention to the center of the screen.*

Figure 2 *A static frame from the dynamic pointing stimulus followed by the appearance of one of the toys on the side of the screen.*

the screen width) on the left or right side of the screen as the probe stimulus. On half of the trials, the location of the probe was congruent with the direction of the point and on half of the trials it was incongruent. The probe remained visible for 3000 ms and was accompanied by a voice saying 'wow!' After the probe, a black screen appeared for 45 ms before a new trial started.

Procedure

Infants sat on their parent's lap facing a rear-projection screen (200 × 100 cm) at a distance of approximately 140 cm. Parents were instructed to not look at the stimulus display during the testing, so they were not able to influence where their babies looked. We monitored the parents during the testing and reminded them to look away from the stimulus if they were tending to look. The experimenter and equipment were located behind the screen, such that nothing was visible to infants except the stimulus display. Infants' face and visual behavior were captured by a centrally mounted video camera (Panasonic WV-B0400) located below the projection screen. The output from the video camera was sent to a video splitter where it was gen-locked to the stimulus display and recorded onto videotape for offline coding. As can be seen in Figure 3, the image of the infant's face was stored on the upper two-thirds of the video image, while the stimulus display was aligned with the infant's face and stored on the bottom third of the image.

At the beginning of the session, infants were presented with a blinking ball that appeared centrally, then on the left, then on the right side of the screen. This sequence was designed to familiarize the coders to the baby's individual shifts of attention and was ended as soon as the experimenter considered the baby ready for the experiment. The entire study lasted about 15 minutes.

Design

Infants were presented with a total of 32 trials. Sixteen trials were presented with a right hand pointing and 16 trials were presented with a left hand pointing (stimulus hand). The location of the probe stimulus (right or left side of the screen) and the direction of the pointing finger (left or right) was counterbalanced so that there were eight congruent and eight incongruent trials within each stimulus hand condition. For the presentation of the stimuli, the pointing direction, hand (left or right), congruent or incongruent probe, and the toy itself (clown or Elmo) were randomized in one of four orders that were presented to infants within one of four movies (see Stimuli discussed above). For each infant, the movie was randomly selected.

Scoring and dependent measures

Infants' gaze behavior was scored off-line with a computerized frame-by-frame observational coding system (33 ms resolution). All coders were trained with this system using pilot data, and they did not begin coding infants' responses until the correlation between their coding and the coding by the developer of the coding system (which served as the standard for all coders) was .95. Frame-by-frame analysis enabled coders to identify

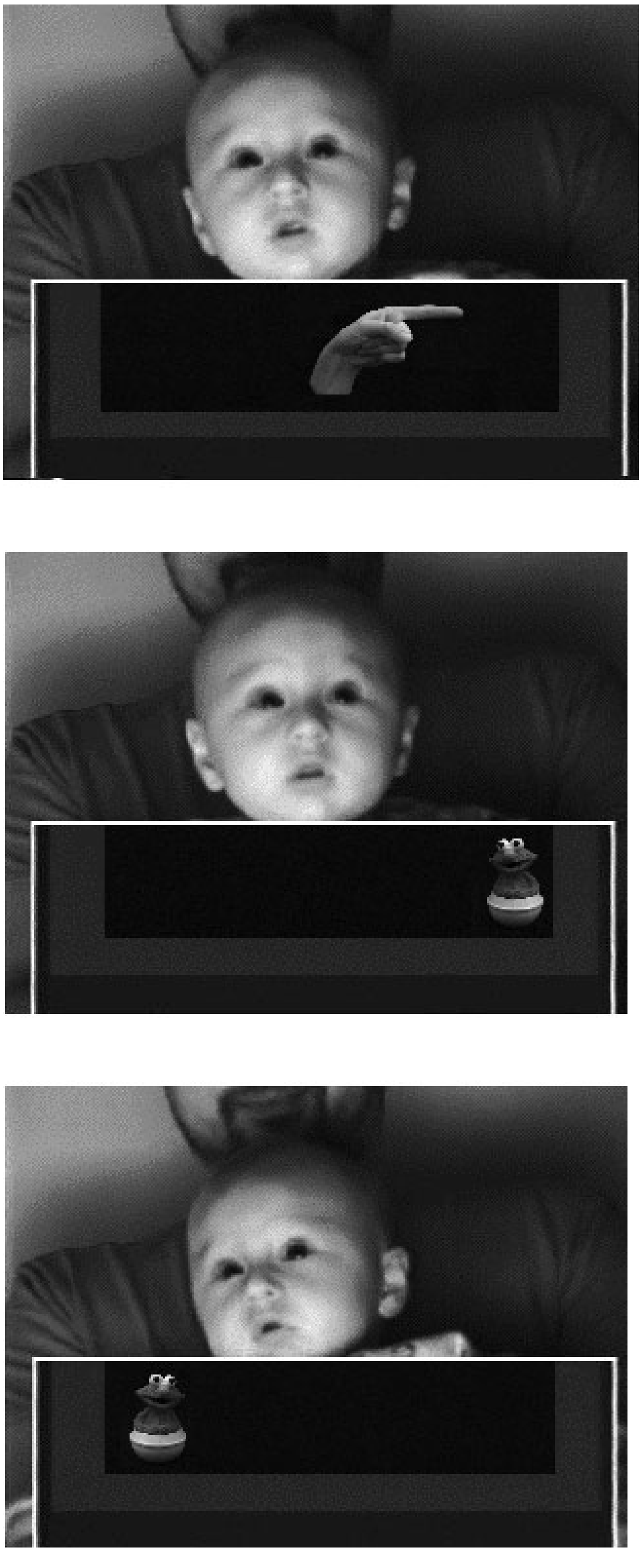


Figure 3 *Split-screen images of infant looking at the stimulus which was located in the lower portion of each panel. Top panel shows the finger pointing to the right. Middle panel shows a congruent trial in which the probe appears on the same side as the pointing stimulus. Bottom panel shows an incongruent trial in which the probe appears on the opposite side from the pointing stimulus.*

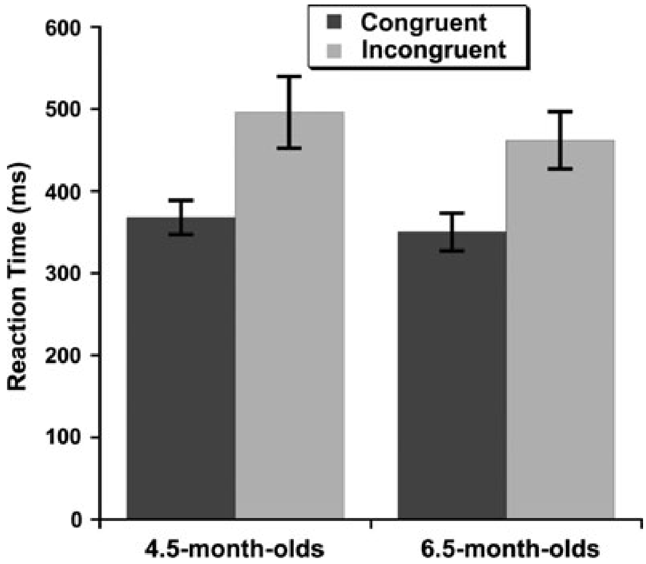


Figure 4 *Mean response times in Experiment 1 as a function of age and congruence.*

the exact time when a probe stimulus appeared and the time at which the infant's fixated pupil began moving horizontally, indicating gaze shift toward or away from the probe. Reaction time was calculated as the elapsed time between the appearance of the probe and onset of infants' gaze shift. Trials in which response times exceeded 2 seconds were excluded. Also, infants who produced fewer than three usable trials in any one of the stimulus hand by stimulus congruence conditions were excluded (but this criterion was relevant only in Experiment 3). In addition to the reaction time, we also scored the spatial errors the infants made in orienting to the probe. An error was coded when the infant's first saccade shifted to the side opposite the probe (see also Hood *et al*., 1998).

Results and discussion

Infants completed an average of 26 trials (SD = 4.4, range: 15–33). Response times (RT) were analyzed only for those trials on which infants oriented correctly to the probe. We conducted an analysis of variance (ANOVA) on infants' mean RT with congruence (congruent, incongruent) as a within-subjects factor and age (4.5 months, 6.5 months) as a between-subjects factor. There was a significant main effect of congruence, $F(1, 18) = 17.29$, $p < .001$; responses were faster on congruent (356 ms) than on incongruent trials (473 ms) (see Figure 4). There was no significant effect of age, $F(1, 18) = 1.08$, *ns*, nor an interaction of age and congruence, $F(1, 18) = .17$, *ns*. Planned comparisons revealed significant compatibility effects, i.e. faster response times to the congruent stimulus probe at both 4.5 months (368 vs. 496 ms), $t(9) = 4.04$, $p < .01$ and at 6.5 months of age (345 vs. 450 ms), $t(9) = 2.27$, $p < .05$.

For the error data, we analyzed the proportion of trials on which errors were made. Overall errors were made on 5.6% of trials. There was a marginally significant trend for more errors on incongruent (7.9%) than congruent (3.2%) trials, $F(1, 18) = 4.28$, $p = .053$. Given that the direction of this effect is in the same direction as the RT data rules out a speed–accuracy tradeoff. There was also a marginally significant effect of age, $F(1, 18) = 4.35$, $p = .052$, with 4.5-month-olds making more errors than 6.5-month-olds (8.5% vs. 2.6%).

Finally, we conducted an additional ANOVA on mean RT including the location of the probe stimulus (left vs. right) as an additional within-subjects factor (see Table 1 for mean RT). There was a marginally significant main effect of direction, with infants orienting faster to the right (400 ms) than the left (441 ms), $F(1, 18) = 3.53$, $p = .077$. There were no interactions involving location, including the crucial interaction between congruence (probe occurring on the congruent side of pointing) and the direction of pointing: $F(1, 18) = 2.28$, $p = .149$. Across ages, there were clearly significant congruence effects for both left (151 ms), $t(19) = 3.74$, $p < .01$, and right (111 ms), $t(19) = 4.74$, $p < .001$, points. Furthermore, the magnitude of the congruence effect in the two directions was highly correlated across infants, $r(19) = .791$, $p < .001$. In sum, this analysis suggests that the location of the probe on the left or right side did not affect infants' sensitivity to the direction of pointing.

These results show that infants as young as 4.5 months of age orient in the direction of a perceived pointing gesture, as long as they are able to disengage from the pointing hand. As discussed in the Introduction, Farroni and colleagues (2000) showed that movement of the eyes was necessary for young infants to follow the direction of gaze. To investigate whether this holds true for pointing as well, we conducted a second experiment in which the pointing hand appeared, but did not move.

Experiment 2

In this experiment, we tested whether the back-and-forth movement of the pointing hand is necessary to elicit attentional shifts or whether a static pointing gesture is sufficient.

Table 1 *Mean response times as a function of age, congruence, and pointing stimulus in Experiment 1*

Probe	Pointing stimulus	4.5-month-olds RT (ms)	4.5-month-olds *SD* (ms)	6.5-month-olds RT (ms)	6.5-month-olds *SD*(ms)
congruent	RH	345.3	20.4	344.6	15.9
	LH	386.4	26.7	345.4	17.7
incongruent	RH	473.2	44.5	437.8	24.3
	LH	563.0	62.0	471.1	58.6

Method

Subjects

A new sample of 14 healthy, full-term infants between 4.5 ($M = 142$ days, $SD = 13.3$) and 6.5 ($M = 189$ days, $SD = 13.0$) months of age were tested.

Stimuli and procedure

The procedure was identical to that presented in Experiment 1, except that the pointing hand remained stationary and did not move back and forth (see stimulus presentation in Figure 3).

Results and discussion

Infants completed an average of 17.6 trials ($SD = 5.0$, range: 6–25). Response times were analyzed only for those trials on which infants oriented correctly to the probe. Mean RT with congruence (congruent, incongruent) as a within-subjects factor and age (4.5 months, 6.5 months) as a between-subjects factor were submitted to an ANOVA. In contrast to Experiment 1, there was no significant main effect of congruence, $F(1, 12) = 1.03$, *ns*, with comparable RTs in the congruent (608 ms) and incongruent (589 ms) conditions (see Figure 5). There was no effect of age, $F(1, 12) = 1.17$, *ns*, nor an interaction of age and congruence, $F(1, 12) = 1.27$, *ns.*

For the error data, we analyzed the proportion of trials on which errors were made (i.e. the infant oriented to the side opposite the probe). Overall errors were made on 6.6% of the trials. There was no difference between the congruent (5.8%) and incongruent (7.3%) conditions: $F(1, 12) = 0.21$, *ns.*

In order to investigate the effects of motion on infants' perception of pointing, an additional ANOVA compared the results of this experiment with those of Experiment 1.

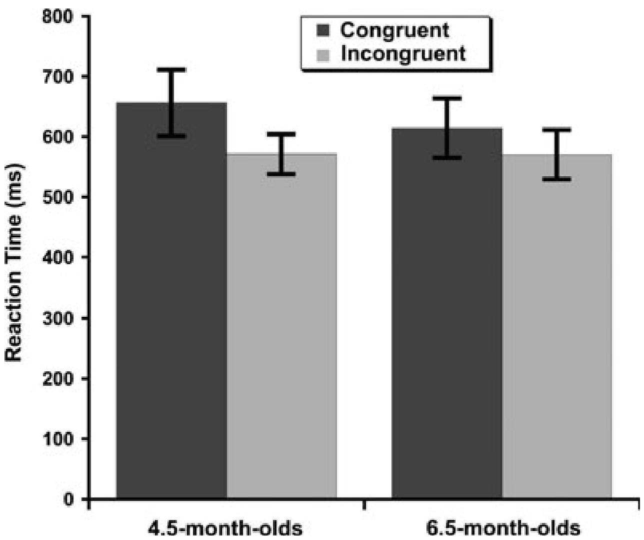
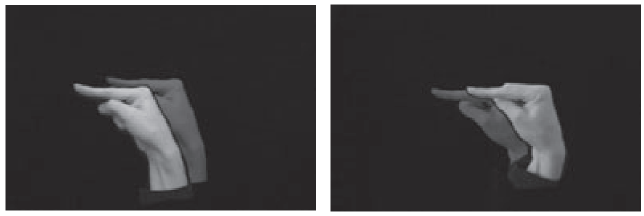


Figure 5 *Mean response times in Experiment 2 as a function of age and congruence.*

A significant interaction of experiment and congruence was observed, $F(1, 30) = 13.30$, $p < .01$, with the congruence effect being significantly larger in Experiment 1 with a moving finger (117 ms) than in Experiment 2 with a static finger (−18 ms). Overall, RTs were faster in Experiment 1 than 2, $F(1, 30) = 33.68$, $p < .001$, indicating that the presence of motion facilitated responses, independent of the direction of pointing. There were no effects or interactions involving the age of children.

These results suggest that infants between 4.5 and 6.5 months of age show the capacity to follow moving – but not stationary – pointing gestures. This reliance on movement for young infants' orienting responses to pointing is comparable to their reliance on movement for eye gaze (Farroni *et al.*, 2000). In previous research, infants' early sensitivity toward eye gaze was found to be cued by lateral motion rather than the final direction of eye gaze (Farroni *et al.*, 2004a). This dependence on movement raises a potential confound: Could the results of Experiment 1 have been driven primarily by tracking the initial movement of the hand as opposed to orienting in the direction of the pointing gesture? Although the hand moving back and forth may have been merely responsible for increasing the infant's attention to the pointing gesture, the initial movement was always in the direction of the pointing finger. It is thus conceivable that this very first movement of the hand was tracked, and biased infants to look in that direction. To address this issue we conducted a third experiment, in which we orthogonally manipulated the direction of the point and the initial direction of movement. If the results of Experiment 1 were primarily a function of following the movement of the hand, then we would expect a reversal in the response time results when the finger moved backward (but pointed forward) rather than forward.



Forward movement Backward movement

Figure 6 *Dynamic pointing finger depicted as moving forward (left panel) or backward (right panel).*

Experiment 3

With this experiment we sought to clarify whether the infants' responses in Experiments 1 and 2 were based on sensitivity to the directional posture of the pointing hand, the motion of the pointing hand, or both.

Method

Subjects

A new sample of 22 full-term infants were tested, 13 4.5-month-olds ($M = 128.1$ days, $SD = 14.8$) and nine 6.5-month-olds ($M = 193$ days, $SD = 23.7$). Four additional infants (two at each age) were excluded because they produced fewer than three usable trials in at least one condition.

Stimuli, procedure and design

Figure 6 depicts the forward and backward motion of the pointing stimulus. In the forward condition, the direction of the pointing finger and the initial movement of the hand were compatible, whereas in the backward condition they were incompatible. The procedure was identical to the first two experiments as 32 trials were shown. Half of the trials in each condition involved a congruent probe (as defined by the pointing gesture) and half of the trials involved an incongruent probe. Pointing congruence was counterbalanced with initial movement direction to yield a 2 × 2 factorial design at both 4.5 and 6.5 months of age. Whereas pointing congruence was confounded with initial movement direction in Experiment 1, these two factors are measured separately in this experiment.

Results and discussion

Infants completed an average of 25 scorable trials ($SD = 5.2$, range: 15–31). Orienting to the probe occurred on 94% of trials ($SD = 9.13$, range: 63–100). The remainder of trials were errors, in which the infant oriented to the side opposite the probe. Response times were analyzed only for those trials on which infants

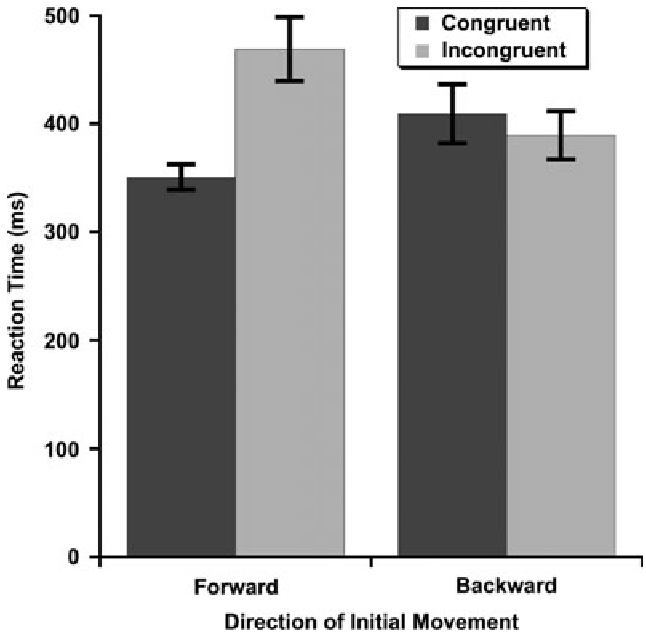


Figure 7 *Mean response times in Experiment 3 as a function of congruence and initial movement direction.*

oriented correctly to the probe. The mean response times for the forward and backward conditions are presented in Figure 7.

Infants' RTs were assessed in a mixed design ANOVA with pointing congruence and initial movement direction (forward vs. backward) of the hand as within-subjects variables, and age as a between-subjects variable. This analysis revealed a significant main effect of pointing congruency, $F(1, 20) = 10.10$, $p < .01$, with response times being faster for congruent (380 ms) than for incongruent (429 ms) pointing. Initial movement direction was not significant, $F(1, 20) = 0.51$, *ns*, but there was a significant interaction of pointing congruency and initial movement direction, $F(1, 20) = 29.18$, $p < .001$. With forward movement, there was a significant effect of pointing congruence (350 vs. 469 ms), $t(21) = 4.89$, $p < .001$. With backward movement, there was a trend towards a reversal of this effect (409 vs. 389 ms), but it was not significant, $t(21) = -1.25$, $p = .10$. We also found a significant main effect involving the age of infants $F(1, 20) = 5.08$, $p < .05$, according to which younger infants (4.5-month-olds) were faster in their responses (376 ms) than the older 6.5-month-olds infants (445 ms). Age did not interact with any other factors.

For the error data, we analyzed the proportion of trials on which errors were made. Our analysis revealed a main effect of initial movement direction $F(1, 20) = 5.03$, $p < .05$, suggesting that infants made more errors when the stimulus hand was moving forward (9.75%) than backward (3.19%). We also found a significant interaction of pointing congruency and initial movement direction, $F(1, 20) = 5.58$, $p < .05$: There was a significant effect of initial movement direction on errors when the probe location was incongruent (13.47% for forward movement vs. 1.87% for backward movement) with the point, $t(21) = 2.50$, $p < .05$, but not when it was congruent (6.03% for forward movement vs. 4.51% for backward movement), $t(21) = 0.62$, *ns*. There were no effects or interactions involving the age of children. This means that the most errors were made in the condition in which both the direction of initial movement direction and pointing were incongruent with the probe location. These two cues were both incongruent in the forward movement condition, but not in the backward movement condition since the pointing and motion cues indicated opposite directions.

The results thus reveal that with forward movement, the direction of pointing and the direction of movement work together, focusing attention in the same direction. With backward movement, they work in opposition to each other, focusing attention in different directions. The finding that a clear congruency effect was found only in the forward movement condition provides clear evidence that both pointing and movement are playing important roles in directing infants' attention. Taken together, our results suggest that pointing compatibility modulates the magnitude of the effect of motion.

Discussion

These results show that – under special conditions – infants as young as 4.5 months of age are capable of shifting their attention in response to a pointing gesture (Experiment 1). This effect appears to be dependent on movement of the pointing finger (Experiment 2), but is distinct from an effect of movement *per se* (Experiment 3). Analogous to previous results on infants' following of eye gaze (e.g. Hood *et al.*, 1998; Farroni *et al.*, 2000), these results reveal sensitivity to the (proto-)function of deictic gestures at substantially younger ages than previously believed (cf. Carpenter *et al.*, 1998; Leung & Rheingold, 1981).

It is interesting to note that our results suggest that infants' predisposition to respond to a dynamic pointing gesture is based on more than just sensitivity to movement. Previous research shows that infants are preferentially attracted to moving stimuli and will localize these stimuli more rapidly (Dannemiller, 2005; Kellman & Arterberry, 1998). However, our results show that the direction of the pointing finger can modulate the magnitude of any effect of movement. Thus, the sensitivity to motion information is not sufficient to explain the current results: In the current study, infants followed the pointing gesture to a distal referent that was not visible during the movement of the finger. This interpretation is also supported by our error analysis according to which infants made the most errors when both the pointing gesture and motion direction of the hand were incongruent with the probe location. In Experiment 3, this was the case when the stimulus hand moved forward; when the stimulus cue moved backward, the pointing and movement cues indicated opposite directions. Thus, this combination of the cues (initial movement *and* pointing congruence) interacted in their effects: Faster response times in the pointing direction when both pointing and movement direction were congruent with the probe, and slower response times in the pointing direction when movement direction was incongruent with the probe. The very slowest response times occurred in the condition when the probe was incongruent with both the pointing and movement direction of the stimulus hand; this condition also resulted in the most errors to the side opposite the probe.

Thus, we interpret our results in terms of infants' sensitivity to the direction of pointing, which includes its distal referent. Again, we would like to stress that motion is important but that infants are also sensitive to direction of pointing, and these two sensitivities interact in their responses.

However, even though we would like to argue that interactional capabilities are supported by perceptional capacities, with our current experiments we cannot answer the question of whether in everyday interaction the direction of movement of the pointing finger enhances the salience of the pointing gesture and biases infants to shift their attention in the direction of the pointing gesture; there are studies in language development indicating that it might be the case (Booth, McGregor & Rohlfing, 2008). So far, we can only state that the infants' bias to movement direction can be modulated by the direction of the pointing finger. Another open question remains as to whether the specific configuration of the cueing stimulus is responsible for the effect or whether any kind of pointing object could elicit a similar response. It might be that – as in dogs (Lakatos, Dóka & Miklósi, 2007) – the pointing index finger is not the most informative feature, but rather the effects result from responsiveness to any bodily gesture which appears conspicuously (Lakatos *et al.*, 2007) and/or protrudes in one direction. Despite the fact that our study points to the necessity of further investigations focusing more closely on particular features of the human gesture (i.e. appearance, motion and protrusion), our results nonetheless suggest that infants might be capable of 'referential expectation' (Gliga & Csibra, 2009, p. 352) in the sense that they are sensitive to proto-functional aspects of a pointing gesture and show anticipating looking behavior to a target accordingly. We found that infants look to the location of an object or event when cued by a pointing gesture.

A possible explanation of how the direction of pointing predisposes infants to predict a referent begins with their sensitivity to directional motion which is present by 3 months of age (Banton & Bertenthal, 1997): Infants become sensitized to a dynamic pointing gesture first by their sensitivity to motion which attracts attention, but this source of information becomes less relevant during development (Farroni *et al.*, 2004a; Moore *et al.*, 1997). This sensitivity to pointing becomes elaborated through both perceptual and motor experiences. By the fourth month, infants hold their heads steady and are active observers of their environment. As part of their social interactions, they observe other people reach, handle and point to objects with arm and finger extensions on a regular basis in everyday life. These activities thus familiarize infants to the two basic components of pointing – arm and index finger extensions – at relatively young ages (Zukow-Goldring, 1996; Thoermer & Sodian, 2001). Thus, before they are able to point themselves, infants might become able to process functional aspects of pointing and by the age of 8 months they demonstrate sensitivity to the congruency of pointing gestures (Gredebäck *et al.*, 2010). This EEG finding is in line with previous findings suggesting that infants benefit from performing actions that are precursors to pointing.

Although canonical pointing does not emerge until 11 months of age (Butterworth, 2003), infants show index finger extensions as early as 3 months of age (Hannan, 1987; Masataka, 1995, 2003; Gómez, 2007). This motor activity is associated primarily with exploration and self-regulation of attention to objects (Masataka, 2003). As such, these 'embryonic' forms of pointing (Butterworth, 2001, p. 228) index infants' own attention rather than serving a communicative function (Masataka, 2003; Gómez, 2007; see also Werner & Kaplan, 1963; Bates, 1976; Blake, O'Rourke & Borzellino, 1994; Deák & Triesch, 2006) as mothers do not report that their infants point (Hannan, 1987). Nevertheless, these early index finger extensions seem to be a precursor of pointing since Masataka (2003) reports that they are associated specifically with speech-like vocalizations and decrease in quantity once communicative pointing is established. It is plausible to assume that from this early motor experience, infants learn that index finger extension is about redirecting attention, since similar links between perception and action are suggested in research showing that experience performing an action facilitates infants' understanding of the goal-directed action (Sommerville, Woodward & Needham, 2005; Hauf, Aschersleben & Prinz, 2007).

Even though 'based on rather low-level factors' (Frischen *et al.*, 2007, p. 698), some naïve knowledge of pointing seems to be evident by 4.5 months of age – as our results show – it takes further development before infants employ it robustly in triadic interactions involving a referential connection between a person and a potential referent (Woodward, 2003; Wilson-Brune & Woodward, 2004). One important factor is the ability to disengage from a salient stimulus. This behavior is partly moderated by the familiarity of the stimulus. Amano, Kezuka and Yamamoto (2004) studied 3- and 4-month-old infants' ability to follow the gaze and pointing behaviors of their mothers as well as an unfamiliar experimenter. Their findings showed that infants need the combination of eye gaze and pointing more often from the experimenter than from the mother when responding to their deictic gestures. In the latter case, children were able to follow the pointing gesture by hand movement alone while the mothers maintained eye contact. This suggests that infants had more difficulty disengaging from the experimenter's face than from the familiar face of their mother. For similar reasons, future research should test whether our findings can be replicated in a situation in which not the hand alone but a whole person is shown.

Another important contributing factor to the development of pointing understanding comes from infants' growing appreciation of the importance of joint attention in communication (Blake *et al.*, 1994; Flom, Deák, Phill & Pick, 2004). For example, it is assumed that a child pointing to an object or event knows that the other person can use this information (Tomasello *et al.*, 2007). This 'intentional transmission of information' (Liszkowski, 2005, p. 149) makes clear that communicative and cooperative aspects of pointing are central and can be filtered among different perceptual features (Liszkowski, 2005; Striano & Reid, 2006). Hains and Muir (1996) report that infants show less sensitivity to eye direction if the eyes do not correspond to the person interacting with them, and it is furthermore suggested that interactions with real people rather than abstract or static stimuli are necessary to engage cognitive mechanisms in young infants (Senju & Csibra, 2008). This suggests that infants build up expectations toward a communicative situation and its embedded signals very early (Gliga & Csibra, 2009).

In sum, the developmental mechanisms by which infants learn about pointing are complex and involve perceptual and motor experiences as well as tuning into the social interactions that necessitate and support pointing gestures. The current research contributes to this literature by showing that one of the antecedents for understanding such a complex behavior emerges at a very young age, and very likely sensitizes infants to learning about the functional consequences of pointing, which as a communicative skill seems to be acquired within a drawn-out process occurring throughout most of the first year (Gredebäck *et al.*, 2010).

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