Chapter 2
The Development of Social Attention in Human Infants

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2.1 Introduction

Humans are social creatures from birth and devote a great deal of time attending to faces, bodies, and actions throughout their lives. Social attention and interpretation of others' eyes, faces, and actions is foundational to how we communicate, learn about the social and physical world, regulate emotions, and develop attachments with others. By adulthood, and most likely long before, we are all *experts* in our social understanding of other people. This understanding includes a number of core principles:

(1) From observing eye gaze, and head and body orientation, we readily detect other's focus of attention (e.g., Butterworth & Jarrett, 1991; Langton, Watt, & Bruce, 2000; Nummenmaa & Calder, 2009).
(2) We reflexively or automatically orient our own attention to the same location resulting in eye contact (direct or mutual gaze) or attention to objects and events (averted gaze) (e.g., Driver et al. 1999; Friesen & Kingston, 1998; Frischen, Bayliss, & Tipper, 2007).
(3) Our attention to observed actions automatically activates corresponding motor programs (Bertenthal & Longo, 2008; Kilner, Marchant, & Frith, 2006; Michael et al., 2014; Rizzolatti & Craighero, 2004).
(4) We infer state of mind (i.e., intentions, desires, beliefs) from these actions by others (e.g., Blakemore & Decety, 2001; Gallese, Rochat, Cossu, &

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A. Puce, B. I. Bertenthal (eds.), *The Many Faces of Social Attention,*
DOI 10.1007/978-3-319-21368-2_2

Sinigaglia 2009; Wellman, Lopez-Duran, LaBounty & Hamilton, 2008; Woodward, 2009).

This chapter is concerned with the origins and early development of these core principles. Our goal is not to provide a comprehensive review, but rather to make a case for studying social attention as a developmental process and not as a developmental outcome. The contributions of social attention as a process are often lost in contemporary research studies involving social stimuli. In an effort to conduct experimentally rigorous and well-controlled experiments using real-time measures such as eye tracking or electroencephalogram (EEG), many of these studies have reduced the stimulus situations to static faces, or disembodied arms reaching for an object. What are the implications of using these simple stimuli? In essence, these paradigms forgo the process of attentional selection because the stimuli are all preselected. Yet, selective attention is often the key to what we understand, because it represents the ability to maintain a behavioral or cognitive set amidst distracting or competing stimuli.

In more natural social situations, selective attention is essential and involves two interrelated processes (Corbetta & Shulman, 2002):

(1) Exogenous orienting, or stimulus-driven attention, is under the control of the stimulus and is considered to be reflexive and automatic. This process is present from birth and explains why neonates reveal some preferences from birth.
(2) Endogenous orienting, or goal-directed attention, is the intentional allocation of attentional resources to a predetermined location or space. This type of orienting occurs when attention is directed according to an observer's goals or desires, allowing the focus of attention to be manipulated by the demands of the task or situation.

Endogenous orienting depends on higher-level processes that develop with age and experience, and significantly influence what the child decides to look at. *The development of social understanding is thus reciprocally related to the development of social attention, in that the child's understanding of others will influence where the child directs attention, and where attention is directed will contribute to what the child learns about the social behaviors of others.*

In the remainder of this chapter, we will present a selective review of infants' social attention and social understanding in order to show how the two are reciprocally related in the development of joint attention. While the precise definition of this behavior continues to be debated, it involves at a minimum attention to another individual and to the referent of his or her attention (Shepherd & Cappuccio, 2012). We begin with a brief summary of infants' social attention, which will highlight the transition from dyadic (face-to-face interactions in which adults and infants take turns exchanging facial expressions and vocalizations) to triadic social interactions (two individuals looking back and forth at an object and at each other). To better understand these developmental changes, it is necessary to focus on the processes involved. Three processes will be considered:

(1) shared direction of attention between infant and social partner;
(2) contributions of motor experience to action understanding; and
(3) coordination of attention between infant and social partner.

We will conclude by returning to the reciprocal development of social attention and social understanding in order to offer some new insights into how joint attention develops during the infant's first year.

2.2 Development of Social Attention

2.2.1 Face Perception and Gaze Following

Beginning at birth infants attend preferentially to attractive faces, and are most sensitive to the presence of eyes in a face (Batki, Baron-Cohen, Wheelright, Connellan, & Ahluwalia, 2000). In addition, newborn infants prefer to orient to faces displaying direct gaze (Farroni, Csibra, Simion, & Johnson, 2002), and show a rudimentary form of gaze following (Farroni, Massaccesi, Pividori & Johnson, 2004). These newborn behaviors are hypothesized to be based largely (though not exclusively) on a subcortical visuomotor pathway involving the superior colliculus and pulvinar, which is sensitive to movement and low spatial frequency visual information (Johnson, 2005). Some evidence suggests that newborns are also able to recognize their mother's face (e.g., Bushnell, 2001), but, in general, face perception does not begin to show significant development until around 2 months of age, as the cortical regions that mediate face perception in adults start to become functional (Johnson, 2011). Electrophysiological studies of infants viewing upright and inverted faces using event-related potentials (ERPs), source localization, and gamma oscillations reveal that both gaze and face perceptions show significant changes with regard to amplitude and latency of the response as a function of age, and also begin to recruit more frontal areas of the brain (Farroni et al., 2004; Grossman & Johnson, 2007; Grossman et al., 2008; Halit, de Haan, & Johnson, 2003). In addition, these findings suggest that the brain is prepared to extract gaze information from upright faces, which becomes more adept with development, such that mutual gaze is detected independent of head angle; moreover, direct and averted gaze serve different functions (ostensive cue establishing a communicative connection versus directing social partner's attention in a different direction) and recruit different cortical regions (Grossman & Farroni, 2009).

At a behavioral level, face perception develops rapidly after 2 months of age. Beginning around 10 weeks, infants fixate more consistently on the internal features of a face than on the external features and contours (Haith, Bergman, & Moore, 1977; Hunnius & Geuze, 2004). By 3 months, infants begin to differentiate faces based on the social categories of gender and race (Kelly et al., 2005; Quinn, Yahr, Kunn, Slater, & Pascalis, 2002). Infants' preference for faces continues to develop during the first few months, and becomes sufficiently robust by 6 months of age that they reveal a face pop-out effect when presented with faces among an array of items (i.e., infants orient more frequently and longer to a face than to other items in a stimulus array; di Giorgio, Turati, Altoe, & Simion, 2012; Gliga, Elsabbagh, Andravidzou,

& Johnson, 2009). Critically, these results cannot be attributed to low-level featural salience (e.g., color, intensity, contrast, orientation), because faces were rarely the most visually salient item in the array (Elsabbagh et al., 2013; Gluckman & Johnson, 2013).

Beyond 6 months of age, infants' face perception becomes more narrowly tuned. For example, 6-month-old infants discriminate faces not only from their own species but from an unfamiliar species (i.e., nonhuman primates) as well, whereas this is no longer true for 9-month-old infants (e.g., Pascalis, de Haan, & Nelson, 2002). Similar to speech perception, which changes with experience, the evidence suggests that face processing becomes more specific to those faces appearing in one's own environment (Nelson, 2001). Further support for experiential contributions to the narrowing of the face prototype is that infants given repeated experience with monkey faces retain the ability to discriminate these faces at 9 months of age (Pascalis et al., 2005; Scott & Monesson, 2009). A similar phenomenon is observed with infants viewing faces from other races. By 9 months of age, infants' discrimination of faces is restricted to their own racial group (Kelly et al., 2007; 2009).

The mechanisms responsible for such precocious attention and perception of faces have been a source of debate for decades (e.g., Fantz, 1965). Johnson and colleagues (Grossman et al., 2008; Johnson, 2011; Senju & Johnson, 2009) hypothesize that neither the maturation of the brain nor the face-specific experiences of young infants are sufficient to account for developmental changes in face perception and eye gaze processing. Instead, they propose that development is a function of increasing specialization and localization of face-evoked activity in the brain in response to the interaction between maturational changes and specific experiences of the infant. Their model suggests an intrinsic bias to attend to, and track, face-like stimuli from birth, which increases the likelihood that infants will learn about faces during their foraging of environmental input (Johnson, 2011; Johnson, & Morton, 1991; Morton & Johnson, 1991). Other models attribute early face preferences to domain-general relations between features that are highly correlated with the structure of the face (Cassia, Turati, & Simion, 2004; Simion, Valenza, Cassia, Turati, & Umilta, 2002; Turati, Simion, Milani, & Umilta, 2002). Still, other models suggest innate modules that are responsible for eye direction detectors and/or face perception (e.g., Baron-Cohen, 1995). Although we anticipate that the origins of these behaviors will remain controversial for some time to come, our current interest is directed more toward how social attention continues to develop with age, which we believe is most faithfully captured by increasing specialization emerging from the interaction between brain maturation and experience.

2.2.2 Contextual Modulation of Faces and Objects

While face perception and eye gaze processing are necessary precursors for subsequent improvements in infants' responses to eye gaze and other social responses, the development of these processes is not sufficient to account for the complexity of observed behaviors. By 1 month of age infants seek eye contact in social situations, and receiving this contact while nursing potentiates the effect of sucrose delivery on calming a distressed baby (Zeifman, Delaney, & Blass, 1996). Beginning at 9 weeks of age, infants fixate more consistently on an adult's eyes when the adult is speaking rather than when the adult is silent (Haith, Bergman, & Moore, 1977). Three-month-old infants smile in response to eye contact and decrease smiling when a partner's gaze is averted (Hains & Muir, 1996). By 3–4 months infants respond differentially to contingent and noncontingent (or still) faces (Bigelow & Power, 2014; Tronick & Cohn, 1989). Infants are even more distressed at a still face than at separation from the mother (Field, Vega-Lahr, Scafidi, & Goldstein, 1986). Babies get equally upset if the still face is posed by the live mother or a closed-circuit television image, but there is no change in infants' behavior if the virtual mother continues to be expressive while the sound is turned off (Gusella, Muir, & Tronick, 1988). At 4 months, eye contact enhances face recognition (Farroni, Massaccesi, Menon & Johnson, 2007) and engages cortical areas associated with processing communicative signals in adults (Grossman & Farroni, 2009). By 6 months of age, direct gaze functions as a form of ostensive communication and increases the rate of subsequent gaze following (Senju & Csibra, 2008).

Recent ERP data indicate that adults' gaze facilitates object processing in infants as young as 4 months of age (Reid, Striano, Kaufman, & Johnson, 2004). In this study, objects that were previously cued by eye gaze elicited a lower-amplitude positive slow wave between 700 and 1000 ms over the right frontotemporal scalp, suggesting that eye gaze facilitates learning since a diminished positive slow wave is associated with deeper memory encoding (Nelson & Collins, 1991). In a variant of this paradigm (Striano, Kopp, Grossmann, & Reid, 2006), 9-month-old infants interacted with a live adult who either first looked at the infant before looking at an object (joint attention condition) or only looked at the object (no joint attention condition). In contrast to the no joint attention condition, objects presented in the joint attention condition elicited a greater negative component (Nc) peaking at about 500 ms over the frontal–central scalp. Nc is putatively generated in the prefrontal cortex while attending to a visual stimulus (Reynolds & Richards, 2005), suggesting that more attentional resources are devoted to objects that share attention. Although these studies are suggestive of social learning from eye gaze and joint attention (see Reid & Dunn, Chap. 3, this volume) for an expanded discussion of this issue), they lack converging behavioral evidence confirming that the cortical response is functionally significant (for an exception, see Wahl, Michel, Pauen, & Hoehl, 2013).

2.2.3 Dyadic and Triadic Interactions

Beginning around 2–3 months of age, infants are often engaged in dyadic interaction with their caregivers, ensuring that faces are a prominent part of their visual experience. These face-to-face interactions offer infants opportunities for learning about reciprocity and turn-taking, as well as self-efficacy (i.e., their behaviors affect others in a consistent and predictable manner) (Lock & Zukow-Goldring, 2010). By 6 months of age, infants are beginning to lose their interest in face-to-face interactions, and their caregivers begin to direct their attention more toward objects, which they are now able to reach and explore with their hands (Fogel, 2011). As a consequence, they are much more likely to divide their attention between exploring objects with their eyes and hands and interacting with social partners (Lock & Zukow-Goldring, 2010). For the next few months they typically distribute their attention to either objects or social partners, but they still must learn to share their attention about a common referent with someone else. It is not until the latter part of the first year that evidence for triadic abilities, such as joint attention, is reported, suggesting that infants at this age attribute intentional states to social partners (Carpenter, Nagell, & Tomasello, 1998; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Infants begin to establish joint attention with an adult toward an object (Bakeman & Adamson, 1984), use expressed emotions toward an object to guide their own behaviors (i.e., social referencing; Mumme & Fernald, 2003), and even point to an object communicatively (Carpenter et al., 1998).

To avoid any misunderstanding, we wish to distinguish between joint attention and the shared gaze that occurs when two individuals look at the same object. Beginning with the pioneering study of gaze following by Scaife and Bruner (1975), there is now considerable evidence suggesting that infants begin to follow the gaze shifts of another individual as early as 3 months of age (e.g., D'Entremont, Haines, & Muir, 1977; Farroni, Johnson, Brockbank, & Simion, 2000; Hood, Willen, & Driver, 1998). Although this behavior signals some preliminary form of joint visual attention, a number of researchers suggest that simply following someone's gaze is not the same as comprehending that this gaze shift is intended to direct one's attention to something as a means of communicating about it (e.g., Butterworth, 2003; Tomasello, 2008). We concur and believe that it is useful to differentiate between an earlier and later form of joint attention. At the first level, infants need only to selectively orient to some interesting distal referent based on another's social cues, whereas at the second level infants need also to comprehend the mental state of the social partner and relate it to their own mental state. This latter level of comprehension is believed to develop around 9–12 months of age as infants establish triadic forms of communication signaled by looking back and forth between the social partner and distal referent (Carpenter & Call, 2013). In order for infants to participate with others and establish joint goals, it is necessary for them to understand others' intentions.

Laboratory studies testing specifically for an intentional, target-directed understanding of gaze find the earliest evidence at around 8–9 months of age, but only under limited conditions primarily involving a succession of acts performed over multiple equifinal paths (Johnson, Ok, & Luo, 2007). In this study, infants were familiarized to an actor who looked repeatedly, but with variations, toward one of two objects (i.e., referred to as the familiar goal) located to the left or right of the actor. On test trials, the location of the two objects was switched, and infants showed preferential looking to the event depicting the actor looking at the previously unattended object (i.e., referred to as the new goal) as opposed to the previously unattended location. Although this evidence is suggestive, it is not definitive as infants will represent even novel nonhuman actions as goal-directed under these conditions (Biro & Leslie, 2007; Gergely, Bekkering, & Kiraly, 2002). As such, the interpretation of these findings remains somewhat ambiguous because they may be a result of infants attributing intentionality to both animate and inanimate agents, or alternatively, infants were unintentionally trained during these experiments—an interpretive problem common to many developmental studies (Bertenthal, Gredebäck, & Boyer, 2013).

Interestingly, infants do not show preferential looking to the new goal until 12 months of age if the actor turns his or her eyes and head in the direction of the object without subsequently varying the focus of his or her attention (Johnson et al., 2007; Woodward, 2003), and this result is not consistently replicated (Thoermer & Sodian, 2001). Furthermore, it is not entirely clear whether infants are following the direction of eye gaze or the orientation of the head. For example, Brooks and Meltzoff (2002) showed that 9-month-old infants are just as likely to turn their heads when following an adult's head turn regardless of whether the eyes were open or closed. Perhaps, this issue is less of a concern when considering whether infants understand another's intentions, because these intentions could be signaled by eye direction, or head orientation, or both, but nevertheless this last result serves to underscore the fragility of the evidence for joint attention when observing gaze following. In the next section, we will contrast this evidence with point following which appears to avoid some of these problems. One problem common to virtually all laboratory studies, however, is that only one adult actor is typically presented, displaying highly scripted and very salient behaviors; thus, it is difficult to know how well the results from these experiments generalize to more naturalistic situations.

In spite of these various caveats and cautions concerning the interpretation of gaze following, there is considerable evidence suggesting that infants acquire the social–cognitive prerequisites for understanding their own as well as others' intentions by 9–12 months of age. For example, infants begin pointing to objects communicatively (Butterworth, 2003; Carpenter et al., 1998); they become upset when their goals are blocked and are pleased when they achieve an intended goal (Fogel, 2011); they seek appraisal from caregivers to regulate their own emotions (Mumme & Fernald, 2003; Sorce, Emde, Campos, & Klinnert, 1985); and they expect social partners to express interest in shared referents (Liszkowski, Carpenter, & Tomasello, 2007). Converging evidence is provided by imitation studies, where infants by 10–12 months of age observe the unsuccessful attempts of a model to perform a goal-directed action (e.g., pulling apart a toy barbell) and then perform the target act in spite of not seeing it (Brandone & Wellman, 2009; Legerstee & Markova, 2008; Meltzoff, 1995). These results suggest that infants can infer the unseen goals or intentions of the model; otherwise, it would not have been possible for them to perform the intended actions. In view of this evidence, many theorists claim that the social–cognitive prerequisites for joint attention are available by 9–12 months of age and we concur with this conclusion. What remains less clear is how these social–cognitive skills develop. As discussed in the beginning of this chapter, we hypothesize that developmental changes in social attention are reciprocally related to changes in social understanding, and thus infants' continuous and repeated experiences observing and interacting with their caregivers and other social partners tutor their attention as well as their perceptions of others' behaviors.

2.3 Shared Direction of Attention Between Infant and Social Partner

2.3.1 Gaze Following

What social information is used by infants to direct their attention? We have already briefly reviewed evidence suggesting that they are sensitive to gaze direction from birth: they prefer to look at faces displaying direct gaze from birth and they tend to orient in the direction of averted gaze by 3 months of age (Farroni et al., 2002; Hood et al., 1998). Here, we consider in more detail the interpretation of these behaviors, how they change with age, and whether shifts in attention are restricted to following eye gaze.

Extensive research with adults over the past two decades reveals that the eyes direct attention to specific places and objects through gaze (e.g., Frischen et al., 2007; Langton et al., 2000). If someone is looking directly at us, then we are the object of their attention. Direct or mutual gaze is a prerequisite to social interactions and serves as an ostensive cue informing the observer that there is an intent to communicate with them. By contrast, averted gaze directed away from the observer is interpreted as trying to direct one's attention toward somewhere, something, or someone else, and we typically respond by shifting our attention in the direction pointed to by the eyes. Averted gaze is frequently used in spatial cueing paradigms (Posner, 1980) to demonstrate orienting of attention by gaze. When a face is centrally presented prior to the onset of a peripheral target, detection is faster when the target appears on the side cued by the averted gaze (e.g., Friesen & Kingstone, 1998). The finding that this effect is very fast (100 ms) and occurs when gaze direction is not predictive or even counterpredictive of target location has been interpreted as reflecting an automatic, reflexive, and stimulus-driven (exogenous) orienting of attention which is very difficult to inhibit (e.g., Driver et al., 1999; Friesen, Ristic, & Kingstone, 2004; Langton & Bruce, 1999).

2.3.2 Interaction Between Different Social Cues

Currently, it is not clear whether this reflexive orienting is specific to eye gaze or to social stimuli more generally. Humans possess remarkable social attention skills that involve not only eye gaze but also head and body orientation and especially pointing gestures (Langton et al., 2000). Indeed, these gestures may provide a more accurate cue to the spatial location of a referent than either eye or head orientation. Although some researchers suggest that gaze cueing is unique because of the high contrast between a white sclera and a dark iris (e.g., Emery, 2000), there is little empirical evidence to support this claim. In fact, it has been suggested that pointing gestures may provide a more salient and accurate cue to the spatial location of a referent than either eye or head orientation (e.g., Butterworth, 2003; Deák, Walden, Kaiser, & Lewis, 2008; Langton et al., 2000; Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002). Similar to eye gaze, these gestures receive dedicated processing by the superior temporal sulcus region of the brain (Materna, Dicke, & Their, 2008). Moreover, Burton, Bindemann, Langton, Schweinberger, and Jenkins (2009) directly compared the likelihood of an unattended pointing hand, or gaze cue distractor, interfering with the speed of responding to a gaze or pointing hand cue. Critically, the results revealed that the pointing hand distractor interfered with shifting attention to the gaze cue target, but not vice versa. In another study, the orientation of the head was also observed to interfere with perceiving the direction of eye gaze (Langton, 2000). In sum, the most parsimonious interpretation of the data is that all of these deictic cues contribute to how readily we detect others' focus of attention, orient our own attention to the same location, and draw social–cognitive inferences regarding their goals, intentions, and actions (Langton et al., 2000).

What does the evidence reveal about infants' responses to different deictic cues? Most of the previous research confounds gaze cueing with head and body orientation (e.g., D'Entremont et al.,1997; Scaife & Bruner, 1975), and some evidence suggests that infants do not distinguish between gaze cueing and head and body orientation until their second year (Caron, Butler, & Brooks, 2002; Moore & Corkum, 1998). This confound was avoided, however, by Hood et al. (1998) who adapted Posner's spatial cueing paradigm (Posner, 1980) to test 3- and 4-month-old infants. In this paradigm, the spatial cue was a digitized, color image of an adult face with blinking eyes that subsequently shifted to the left or right. Infants oriented their attention faster to a peripheral target in the cued than non-cued direction, even though the gaze direction was not predictive of target location. This result was interpreted to suggest that 3- to 4-month-old infants can detect the direction of gaze and that this direction will influence the direction of their own attention.

Although these findings are suggestive of infants shifting attention in response to a perceived gaze shift, it is difficult to know whether infants were responding specifically to a shift in eye gaze or more simply to a translating stimulus, that is, pupils moving to the left or right. Farroni et al. (2000) tested this question directly by presenting 4- to 5-month-old infants with the same digitized face stimulus except that the face moved laterally and the pupils remained stationary, but appeared to move in the opposite direction because of relative motion. The results revealed that infants shifted their attention in the direction of the head movement suggesting that they were following the translatory movement of the head and not the gaze direction. Accordingly, it is still not clear whether young infants can respond to eye gaze independent of head orientation.

2.3.3 Point Following

Pointing is another deictic gesture used to reorient the attention of someone else so that an object or person becomes the shared focus of attention (Butterworth, 2003). Typically, it is identified by a stereotypical posture involving the index finger and the arm extended in the direction of a distal referent. Is there any evidence that young infants follow the direction of a pointing hand? Until recently it was assumed that point following did not emerge until close to the end of the infant's first year of development. A few early studies reported that 9-month-old infants follow a pointing gesture to nearby targets, and that by 12 months of age they follow the direction of a pointing gesture to more distant targets (e.g., Leung & Rheingold, 1981; Morissette, Ricard, & Decarie, 1995; Murphy & Messer, 1977). In addition, a more recent EEG study revealed that 8-month-old infants showed differential activation of a P400 ERP to pointing gestures that were congruent as opposed to incongruent with the location of a target (Gredebäck & Melinder, 2010). One problem with all of these studies is that younger infants were not tested, and thus it was not possible to establish at what age infants begin following a pointing gesture.

More recently, Daum, Ulber, and Gredebäck (2013) used a modified version of the spatial cueing paradigm pioneered by Hood et al. (1988) to test 10- and 12-month-old infants orienting responses to a pointing hand. Critically, the older but not the younger infants responded to the direction of the pointing hand, at least when it was accompanied by human speech. This finding thus suggests that point following does not emerge until close to the end of the first year, but a similar study by Rohlfing, Longo, and Bertenthal (2012) revealed a very different finding when testing 4- and 6-month-old infants' covert attention to a pointing hand. Unlike the preceding study, the sound of a human voice accompanied only the presentation of the attention-getting stimulus prior to the appearance of the pointing hand. The results of the first experiment revealed that infants oriented more quickly in the direction of the target when it was congruent as opposed to incongruent with the pointing gesture (even though the direction of the point was non-predictive of target location). Two follow-up experiments revealed that a slight movement of the hand was necessary, but not sufficient, for infants to shift their attention: faster responding to the congruent target was observed when the movement of the hand was in the same direction as the pointing finger, but there was no difference in responding to the congruent and incongruent targets when the movement of the hand was in the opposite direction of the target.

Before trying to reconcile the results from these two studies, it is necessary to consider two issues that may have undermined the validity of both studies. The first issue concerns whether infants were responding specifically to a pointing hand or were simply responding in the direction signaled by a pointing stimulus (i.e., social hypothesis vs. directionally oriented stimulus hypothesis). Neither study compared infants' responses to a pointing hand with their responses to a nonsocial stimulus, such as an arrow. This is a critical question to address since it is currently unknown whether infants are differentially sensitive to social and nonsocial spatial cues. The second issue concerns whether infants were likely to respond to the referent of the pointing gesture if the pointing hand did not disappear before the target appeared (this is a procedural manipulation introduced by Hood et al. (1998) to ensure that infants would disengage from an attractive face). In the case of a pointing stimulus, however, the question of disengagement is central to whether or not infants can follow a pointing hand, because infants may be interested in the hand per se, and thus not orient away from it (e.g., Amano, Kezuka, & Yamamoto, 2004; Butterworth & Grover, 1990; Woodard & Guajardo, 2003).

2.3.4 Testing Social Versus Nonsocial Models

To address these concerns, Bertenthal, Boyer, and Harding (2014) conducted an eye-tracking study with a similar spatial cueing paradigm, except that 4- and 6-month-old infants were tested with both a pointing hand and a foil, which preserved the same size and shape as the hand, but lacked featural details (Fig. 2.1). By comparing saccadic response times to these two stimulus cues, it was possible to determine whether infants' responses to a social stimulus were specialized. In addition, the stimulus cue in this study did not disappear when the target appeared (Fig. 2.2). As a consequence, it was possible to determine whether the stimulus to target onset asynchrony (SOA: delay between the onset of the stimulus cue and the target) would influence the likelihood of faster responding to the congruent target. In adults, faster responding to the cued target begins to dissipate after an SOA of more than 100 ms and is often no longer significant after 500 ms (Frischen et al., 2007). The reason for this effect is that a response time advantage occurs only if adults respond reflexively or automatically to the target, but following a 500 ms SOA they often have sufficient time to strategically select their response without any benefit for a reflexive response in the cued direction (Boyer & Bertenthal, 2012). When the SOA is only

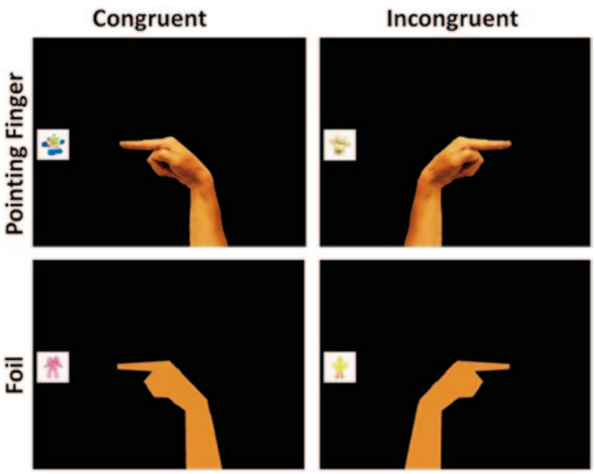

Fig. 2.1 *Digital images of the stimulus displays depicting the pointing hand and foil oriented in the direction (congruent condition) or the opposite direction (incongruent condition) of the target.* (Reprinted with permission from Bertenthal et al., 2014)

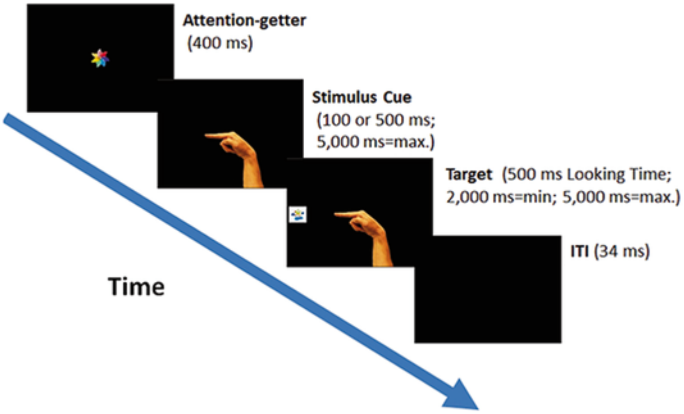

Fig. 2.2 *Sequence of stimuli presented on each trial with the gaze duration contingencies necessary for the appearance of the next stimulus.* Infants were coded as looking at one of the stimuli when their point of gaze landed in an area of interest that surrounded each of the stimuli. For the stimulus cue and target stimuli, minimum and maximum presentation durations are also listed. (Reprinted with permission from Bertenthal et al., 2014)

100 ms, a reflexive response will need to be inhibited if the target is not congruent (recall that the location of the target is not predicted by the direction of the pointing stimulus); thus, a longer response time associated with the incongruent target is a function of this inhibitory process. Infants were tested with both a 100 ms and a 500 ms SOA to determine whether the time course for their responding to a pointing stimulus was similar to the response time processes observed in adults.

An important innovation in this study was to use a gaze contingent paradigm such that each stimulus in the sequence appeared only after infants had attended to the preceding stimulus for a criterion period of time (see Fig. 2.2). A Tobii eye-tracking system (Stockholm, Sweden) in conjunction with E-Prime stimulus presentation software (Psychology Software Tools, Pittsburgh, PA) was used to implement these contingencies by recording and measuring gaze duration in real time. E-Prime was programmed to wait for a criterion gaze duration before displaying the next stimulus. This procedure ensured that infants would attend to each stimulus for the same amount of time on each trial before the next stimulus would appear. An added benefit to implementing this procedure was that infants became more task-oriented and were less likely to become distracted at the end of a trial. As a consequence, Bertenthal et al. (2014) were able to administer an average of almost 40 trials per infant, which significantly increased the power of their design.

The results revealed that 6-month-old infants responded faster to the congruent target appearing in the direction of the pointing hand stimulus at 100 ms SOA, but did not respond faster to the congruent target at 500 ms SOA (Fig. 2.3). By contrast, infants did not respond faster at either SOA to the target when the foil appeared as the stimulus cue. Four-month-old infants showed a congruency effect, but with less specificity. In essence, they responded faster to the congruent target at both

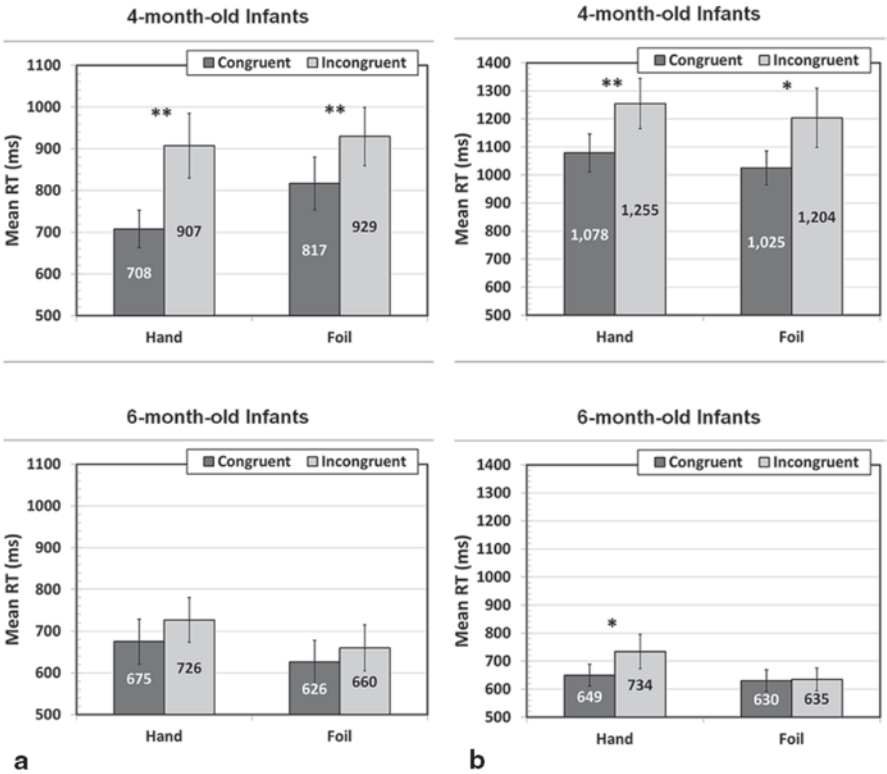

Fig. 2.3 **a** *Mean saccadic response times in Experiment 1 to the cued (congruent) and non-cued (incongruent) targets as a function of age and stimulus cue.* Error bars represent ± standard error of the mean; **p <.02; *p <.04. **b** *Mean saccadic response times in Experiment 2 to the cued (congruent) and non-cued (incongruent) targets as a function of age and stimulus cue.* Error bars represent ± standard error of the mean; **p <.03; *p <.05. (Reprinted with permission from Bertenthal et al., 2014)

SOAs independent of the stimulus cue. These results thus suggest that 6-month-old infants orient to a pointing hand differently than to a foil, presumably because their response is already specialized for a social stimulus. Moreover, it appears that the time course for reflexive orienting to a pointing hand is similar for infants and adults, in that infants, like adults, did not show a congruency effect at 500 ms SOA. By contrast, 4-month-old infants detect the direction of a pointing stimulus, but do not seem to differentiate between a social and nonsocial exemplar. The most straightforward interpretation for this result is that infants did not discriminate the pointing hand from the foil that shared the same size and shape.

In order to test this interpretation, a preferential looking experiment was conducted with the pointing hand, the foil, and an arrow. Infants were presented with pairs of stimuli on each trial, and the results revealed that both 4- and 6-month-old infants looked longer at the pointing hand than at the foil or the arrow, and also looked longer at the foil than at the arrow. Accordingly, the developmental shift observed in the previous experiment could not be attributed to differences in perceptual discrimination, but rather provides convergent evidence for suggesting that infants' responses to a pointing hand become specialized by 6 months of age. As such, this result is consistent with Johnson's model of interactive specialization, suggesting that the cortex becomes more specialized over time with regard to the stimuli that are processed by a specific neural network (Johnson 2011). This increased specialization is most likely a function of infants acquiring more experience with pointing hands through their social interactions with caregivers and others. According to this hypothesis, the reason that 4-month-old infants responded the same way to the pointing hand and foil is because both stimuli stimulated the same developing social attention network in the brain (Grossman & Farroni, 2009; Johnson, 2011). By 6 months of age, this network has become more specialized for social stimuli, and thus the response time advantage for congruent stimuli was restricted to only the pointing hand.

2.3.5 Point Following Versus Point Comprehension

Although these results converge with those reported by Rohlfing et al. (2012) to suggest that infants orient in the direction of a pointing hand by 4 months of age, Daum et al. (2013) suggest that infants do not orient in the direction of a pointing hand until 12 months of age. How can we reconcile these seemingly significant age differences? One possibility is that differences in the size and contrast of the stimulus cue and target are responsible, but we suspect that the reason is attributable to more than stimulus differences. In the two studies reporting that 4- and 6-month-old infants respond to the pointing hand by following the direction to the target, infants were able to orient their attention to the target without any knowledge of the social partner's mental state. It was sufficient for them to follow the direction of the point without any interpretation of its meaning. By contrast, infants in the Daum et al. (2013) study were shown a pointing hand with an accompanying speech act. The combination of the two stimuli together may have resulted in infants interpreting the stimulus not as a directional cue, per se, but rather as a communicative act requiring that infants understand the referential intention of the pointing hand (i.e., infants appreciate that the hand is attached to a social partner who is directing their attention to a specific referent). In essence, this difference was foreshadowed in the previous section (see section "Testing Social Versus Nonsocial Models") when discussing the distinction between following someone else's gaze and understanding the communicative intent of a gaze shift. The current results on pointing are in accord with those previous results on gaze following, which revealed evidence of gaze following by 3 months of age, but understanding a causal relation between gaze direction and target does not appear until sometime between 9 and 12 months of age (e.g., Johnson et al., 2007; Senju, Csibra, & Johnson, 2008).

Converging evidence for this interpretation comes from a series of studies investigating infants' comprehension as well as production of pointing (e.g., Deák et al., 2008; Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004; Liszkowski et al., 2007; Tomasello, Carpenter and Liszkowski, 2007). By 1 year of age, infants begin pointing to absent, or experientially defined, referents making it clear that they understand that pointing is not simply a cue for attracting another's attention to a specific object, but instead is a means to orient them mentally to some shared representation. Also, infants begin to show comprehension of pointing, which requires more than merely following the direction of a point; infants search for invisibly displaced objects in locations that are specified by an adult's point, and search even longer when the object is not found at the pointed location (Behne, Liszkowski, Carpenter, & Tomasello, 2012; Gliga & Csibra, 2009). An especially compelling example of how infants comprehend pointing in terms of a shared understanding was reported by Liebal, Behne, Carpenter, and Tomasello (2009) who showed that 14- and 18-month-old infants interpreted an adult's pointing gesture differently depending on whether or not this individual had been involved with the infant in a previous activity. Taken together, these findings suggest that infants are not merely following the direction of a pointing gesture, but instead understand the communicative intent of the actor. By contrast, great apes will follow the direction of a point to the location of some hidden food, but will generally not search inside the container for food because they do not make the inference that the point is communicating the location of food (Miklosi and Soproni, 2006). We predict that 6-month-old infants would respond in a similar manner to great apes, because they, too, do not understand the communicative intent of the point.

2.3.6 Development of Joint Attention

In sum, infants follow the direction of a pointing hand within a month of being able to follow a gaze shift. For both of these stimuli, movement is necessary, but not sufficient, to trigger an orienting response. It thus seems unlikely that gaze cueing is privileged for orienting infants' attention; rather, gaze cueing, head orientation, body posture, and pointing are all likely candidates for triggering shifts of attention, and infants' responses to these behaviors become more specialized with age and experience. At least until 6 months of age, infants are capable of following the direction of an eye, head, or body movement, but they have not yet developed a shared understanding with the other person as to the motivation for this deictic gesture. According to some theorists (e.g., Carpenter et al., 1998; Tomasello, 2008), this shared understanding does not emerge until infants begin to understand others' goals and intentions, sometime between 9 and 12 months of age. Although this view is consistent with much of the extant data, it does little to explain how joint attention develops. It is assumed that this behavior develops with the emergence of the necessary prerequisite social–cognitive skills, but without knowledge of *how these* *skills develop* this explanation is far from complete. As such, the prevailing view of the development of joint attention seems fragmented and discontinuous.

As an alternative, we favor a model suggesting a more continuous progression in the development of joint attention (cf. Bertenthal et al., 2014). The early development of point or gaze following establishes a foundation for a boot-strapping process by which infants learn about the intentions of others from opportunistically directing their attention to others' deictic gestures and the co-orientation of visual attention that ensues (cf. Moore & Corkum, 1998; Triesch, Teuscher, Deák, & Carlson, 2006). In essence, these encounters offer an opportunity for infants to learn that following another's deictic gesture leads to their attending to some person or event of interest to them. These encounters become more and more frequent with development, especially with the decline of dyadic interactions. As infants are exposed to these interactions repeatedly on a daily basis, the probability of their encoding a relation between a deictic cue and a distal referent will increase, and so will their shared understanding of others' behaviors (e.g., motoric, verbal, affective) in these triadic social interactions. Accordingly, we contend that the relation between attention and social understanding is bidirectional. As infants attend more to the social cues in triadic interactions, their attention will tutor their social understanding, but at the same time their attention will be directed to the relevant cues by their social–cognitive understanding.

2.4 Contributions of Motor Experience to Action Understanding

2.4.1 Relation Between Observation and Execution of Actions

In spite of the voluminous research on social–cognitive development during the first year, our understanding of how infants' social cognition develops is still fairly limited. Most theorists agree that this knowledge emerges with infants' transactions in their social environment, but there is little consensus regarding the mediators of this development. In recent years, various proposals have emerged, suggesting that infants' understanding of others' actions is facilitated by their linking the perception and execution of actions (e.g., Bertenthal & Longo, 2008; Woodward & Gerson, 2014).

Infants learn a great deal about themselves, other people, and their surroundings from observing the effects of their own actions as well as those of others (e.g., Bertenthal & Campos, 1990; Lock & Zukow-Goldring, 2010). Moreover, some theorists suggest that motor experience is necessary for not only producing but also for learning about goal-directed actions (e.g., Rakison & Woodward, 2008; Woodward, 2009). For instance, infants interpret others' reaching actions as goal directed by 5–6 months of age (Woodward, 1998), which is roughly the same age they begin to successfully reach for distal objects (Bertenthal & von Hofsten, 1998. If reaching experience is provided with Velcro-covered sticky mittens, then infants interpret others' reaching actions as goal directed at 3 months of age, even before they are able to reach on their own (Sommerville, Woodward, & Needham, 2005). Also, the sorts of grasps 6-month-old infants are capable of performing predict their ability to differentiate others' grasps (Daum, Prinz, & Aschersleben, 2009). Nine-month-old infants who are already capable of pointing are more likely to understand the referent of a point (Brune & Woodward, 2007), and 10-month-old infants capable of pulling a cloth to retrieve a toy are more likely to understand the means–end structure of someone else performing the same hierarchical goal-directed action (Sommerville & Woodward, 2005). Although the preceding studies support the thesis that motor experience is necessary for action understanding, there are also some exceptions to this generalization (e.g, Boyer, Pan, & Bertenthal, 2011; Hofer, Hauf & Aschersleben, 2005; Daum et al., 2009). Thus, it is more parsimonious to conclude that there is a bidirectional relation between the perception and production of new actions in development (e.g., Bertenthal, 1996; Hauf, 2007).

The preceding evidence is all consistent with theories suggesting a direct link between the perception and execution of actions. This proposal dates back to James's (1890) and Greenwald's (1998) ideomotor theories, which were more recently updated by Prinz's common coding theory (1998). According to this theory, the perception and production of actions share overlapping representations, and thus one process facilitates, or interferes with, the other when they occur close together in time (Hommel, Musseler, Aschersleben, & Prinz, 2001). The discovery of mirror neurons in nonhuman primates and homologous findings in humans offer further support for a direct mapping between the observation and execution of actions (e.g., Decety et al., 1997; di Pellogrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Although the activation of this motor representation does not typically result in overt movements, the cortical regions involved in the planning of the movement and the intended goal are activated. As such, the observation of the action is mapped directly to its motor representation consisting of both the movement plan and the goal. This results in a shared representation enabling the observer to understand how he or she would perform the same action (e.g., Gallese and Goldman, 1998; Prinz, 1997; Rizzolatti, Fogassi and Gallese, 2001).

2.4.2 Representation of Movements Versus Goals

In considering how motor experience contributes to action understanding, it is important to consider that actions are represented at multiple, hierarchically nested levels ranging from specific muscle synergies to more abstract distal goals (Bertenthal & Longo, 2008). It is often assumed that the direct matching that occurs between the observation and execution of actions occurs exclusively at the level of the goal or the effects of the action (e.g., Cook, Bird, Catmur, Press, & Heyes, 2014;

Wohlschläger, & Bekkering, 2003). Indeed, this is consistent with early descriptions of mirror neuron properties, which reported that pantomimed actions (e.g., miming a precision grip in the absence of an object) and intransitive actions (e.g., tongue protrusion) did not elicit mirror neuron responses (Gallese et al., 1996). Similarly, it has been suggested that infants code actions at this same level of analysis, because goals can be represented more abstractly than movements, and thus infants can generalize their representations more readily to others' goal-directed actions even if the specific movements vary (Woodward & Gerson, 2014). For instance, infants learn to generalize one instance of a goal-based action (e.g., goal-directed reaching) to a novel situation in which they observe someone reaching with a mechanical claw, as long as their grasping actions co-occur with the claws' grasping and releasing toys (Gerson & Woodward, 2012).

In spite of the attractiveness of this logic, we wish to caution against dismissing prematurely the importance of movements per se in mapping the observation of actions to their execution. In a developing system such as the human infant, it is sometimes difficult to determine whether the rate-limiting factor is motor coordination or the identification of the goal. For example, 5-month-old infants are incapable of maintaining a balanced sitting posture, yet, biomechanical measurements of their postural sway reveal that their behavior is already goal directed (Bertenthal, Rose & Bai, 1997). Accordingly, infants at this age may lack the necessary motor representation to perceive why someone else is, or is not, sitting in a balanced posture, but it is not because they lack a representation of the goal, rather it is because their movements are not yet sufficiently coordinated; thus the representation is insufficient at the level of the movements, not of the goal.

Consistent with this view, some theorists suggest that, at least in humans, movements may play a larger role in the representation of perceived actions than had previously been supposed. Rizzolatti et al. (2001), for example, speculated that two distinct "resonance mechanisms" may underlie imitation in humans: a high-level resonance mechanism coding action in terms of goals and a low-level resonance mechanism sensitive to the movements constituting an action. Lyons, Santos, and Keil (2006) similarly suggested that the mirror system in monkeys may code perceived actions only in terms of their goals or underlying intentions, whereas the human mirror system codes actions more flexibly and at multiple levels of abstraction, both in terms of goals and the manner in which those goals are achieved. Some early evidence supporting this interpretation comes from a series of studies by Gangitano, Mottaghy, & Pascual-Leone (2001, 2004), who applied transcranial magnetic stimulation (TMS) to the motor cortex as adult participants watched a hand reach and grasp an object. By manipulating when in the time course of the grasp TMS was applied, they demonstrated that the motor-evoked potentials recorded from arm muscles varied systematically with the changing size of the finger aperture. This finding thus suggests that the mental simulation of the observed action included the manner in which the action is performed over time and does not exclusively represent the goal or end state.

Behavioral evidence for this same conclusion comes from a series of studies with adults testing automatic imitation of intransitive actions not involving a goal object, or at least holding the goal constant (e.g., Bertenthal, Longo, & Kosobud, 2006; Boyer, Longo, & Bertenthal, 2012; Brass, Bekkering, & Prinz, 2001). For example, Longo, Kosobud, and Bertenthal (2008) reported that participants responded faster to the tapping movement of an index or a middle finger when they pressed a key with an anatomically matching finger, regardless of whether the finger moved in a biologically possible or impossible manner. If, however, participants were primed to expect both natural and unnatural movements before beginning the experiment, then the compatibility effect was eliminated in the biologically impossible movement condition. In both conditions, there was an identical intransitive goal, which was to depress a key with a matching finger; nevertheless facilitation was only observed if participants were not primed to focus their attention on the manner of movement. These findings are thus illustrative of how actions can be represented at multiple levels: When participants were not cued, the observed finger tapping facilitated the response of the matching finger because actions were represented in terms of goals; when cued, actions were represented in terms of movements and, since the impossible finger movement was not represented within the observer's motor repertoire, there was no activation of a corresponding response.

In sum, these findings with adults confirm that observed actions are automatically mapped to the motor system at the level of both the goal and the movement. This mapping is a function of a shared representation for the observation and execution of the action, but it is also a function of whether the observer focuses attention on the movement or the goal. In the remainder of this section, we will discuss converging evidence for infants motorically simulating, or covertly imitating, the reaching movements that they observe. Critically, the likelihood of infants motorically simulating the observed actions by the experimenter will depend on how attention is deployed during the experiment.

2.4.3 Covert Imitation and Infants' Search Errors

One of the best known paradigms for studying infants' cognitive development is the Piagetian A-not-B search task (Harris, 1975). Infants are seated in front of two hiding locations and observe an experimenter hide an object in one of these locations (i.e., A-location) and then are given an opportunity to search for the hidden object (Fig. 2.4). By 9 months of age, infants are consistently successful in searching for the object over repeated trials. If, however, after a few trials the object is hidden in the opposite location (i.e., B-location), infants err by searching in the previously correct A-location. There are numerous explanations for this search error (see Bremner, 2010 for a review), but a number of recent explanations emphasize the role of repeated reaching and the development of a perseverative response (e.g., Diamond, 1991; Marcovitch, & Zelazo, 1999; Smith, Thelen, Titzer, & McLin, 1999). In essence, this response is a function of the history of activation by the motor system (Thelen, Schöner, Scheier, & Smith, 2001), and thus any experience that might bias the activation of the motor system should induce a similar result (Longo

Fig. 2.4 *Infant searching for toy in one of the two hiding wells*. (Reprinted with permission from Longo & Bertenthal, 2006)

& Bertenthal, 2006). If infants are capable of mapping observed actions to their motor responses and thus motorically simulating these actions, then the same search error on the B trial should be revealed even when infants only observe someone else searching for the hidden object on the A trials.

Longo and Bertenthal (2006) tested this hypothesis by allowing 9-month-old infants to only observe the experimenter hiding and finding the object on the A trials before allowing them to search on the B trial. Overall, the results confirmed their hypothesis, but there was a caveat. A significant number of infants showed the search error after they observed the experimenter perform an ipsilateral reach (hand and object are located on the same side of the body), but infants searched randomly following a contralateral reach (hand contacts an object located across the body midline). This finding was perplexing to many because of the preponderance of data and theories suggesting that mirroring involves a shared representation of the goals or effects of the actions, but not of the movements per se. If, however, infants were responding exclusively in terms of observed goals, then there should not have been a difference in responding as a function of reach type because the goal in both conditions was the same (i.e., retrieve the hidden object). Given the results from this study, it seems reasonable to conclude that there is a tendency in infants to code or covertly imitate the movements as well as the goals of observed actions.

2.4.4 Ipsilateral Versus Contralateral Reaching

Why should infants be more likely to covertly imitate or simulate the actions associated with an ipsilateral than a contralateral reach? Longo and Bertenthal (2006) proposed that this difference was attributable to a delay in the development of contralateral relative to ipsilateral reaching. There are reports dating back to Head (1920, 1926) that aphasic patients, when asked to imitate, frequently failed to cross the body midline, performing an ipsilateral when a contralateral movement was modeled. Although Head (1920, 1926) considered this error a serious sign of neurological insult, this ipsilateral bias has been observed in infancy as well as in older children. The development of contralateral reaching generally lags 2–4 months behind ipsilateral reaching (Bruner, 1969, Morange & Bloch, 1996). If action simulation is related to motor experience, then we would expect a greater number of infants to show errors in the ipsilateral, as opposed to contralateral, condition, because the contralateral motor representation would be less well developed, and thus less likely to bias the reach.

Although the evidence for a lag in the development of contralateral reaching is compelling, there is also the possibility that infants were less likely to selectively focus their attention during contralateral reaches. If this were true, then, by analogy with the adult study comparing possible and impossible biological movements, we would expect a greater likelihood of search errors after increasing infants' attention to contralateral reaches. Recently, Boyer and Bertenthal (in press) tested this possibility by first priming infants to contralateral reaches before testing them. During a 2-min familiarization phase, infants observed an experimenter reach repeatedly for toys with only his contralateral hand, and then he searched for the hidden toys on the A trials using only his contralateral hand. Unlike the results from the preceding experiment, a significant number of infants searched incorrectly in this experiment. It is noteworthy that during the familiarization phase, the experimenter ensured infants' direct attention by including multiple ostensive cues, such as direct eye contact, infant-directed speech, and contingent responding. This may be at least one of the reasons why observational learning without any active participation by the infant was more successful in this experiment than that reported in previous studies (e.g., Sommerville, Hildebrand, & Crane, 2008). In a follow-up experiment, a new group of infants was tested the same way after they were familiarized to only ipsilateral reaching. Even though the goal was the same in this new condition, infants did not search significantly more often than chance at the incorrect location. It thus appears that focusing infants' attention on the movement, but not the goal of an action, will increase the contribution of the movement representation toward inducing a search error.

2.4.5 Predicting the Goal of an Action

Just to be clear, the preceding discussion is not meant to suggest that infants are incapable of mapping observed actions at the level of goals; rather, it is to suggest that they also map actions at the level of movements. In the case of observing ipsilateral and contralateral reaching, recent research from our laboratory confirms that infants represent not only the movements but the goals as well. A key insight for understanding the logic behind this research is that it is essential for actions to be planned prospectively if they are to be performed in a fluid and flexible manner (Bertenthal, 1996; Bertenthal & von Hofsten, 1998; von Hofsten, 1980). This prospective component of an action enables adults to not only predict the goal of their own actions but also the goal of others' actions, thus providing converging evidence that observed actions are mapped to their motor representations (Flanagan & Johansson, 2003). Recent findings with infants suggest that they begin to predict the goal of an action sometime between 6 and 12 months of age, depending on the complexity of the action. For example, infants predict the goal of a simple reaching action as early as 6 months of age (Kanakogi & Itakura, 2011), but they only begin to predict the goal of placing an object in a container around 12 months of age (Falck-Ytter, Gredebäck, & von Hofsten, 2006). These results suggest a general correspondence in age between the emergence of goal prediction for a specific task and the complexity of the motor behavior, but most of the evidence is correlational and indirect (but see van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008 for an exception).

Unlike most previous studies, Barton and Bertenthal (2013) were able to manipulate motor experience directly by testing infants' goal prediction during both ipsilateral and contralateral reaching. If there is a functional relation between motor experience and goal understanding, then goal prediction during ipsilateral reaches should be observed at an earlier age than that during contralateral reaches. Infants between 6 and 12 months of age were tested with a Tobii TX300 eye-tracking system while observing an actor sitting at a table with fingers tapping while the hands were aligned at the body midline (Fig. 2.5). On each trial, the right or left hand would reach either ipsilaterally or contralaterally toward a lid located to the left or right of the actor; once the lid was grasped and lifted a moving and sounding stimulus reward would appear at that location. The sequencing of the stimuli was gaze contingent, which enabled the researchers to present, on average, 33 trials. If infants shifted their gaze to the correct lid prior to the hand contacting it, they were credited with predicting the goal on that trial. As can be seen in Fig. 2.6, the proportion of predictive trials increased with age for both ipsilateral and contralateral reaches. Nevertheless, infants were more likely to predict the goal on ipsilateral than on contralateral trials, at least through 10.5 months of age.

To confirm that the development of infants' goal prediction skills were systematically related to motor experience, infants were also tested on a reaching task. The likelihood of contralateral reaching increased with age and also correlated with the probability of goal prediction. More importantly, the likelihood of contralateral reaching continued to covary with contralateral goal prediction after partialling out age and ipsilateral reaching. As such, these results suggest not only a relation between the development of goal prediction and motor experience, but also that

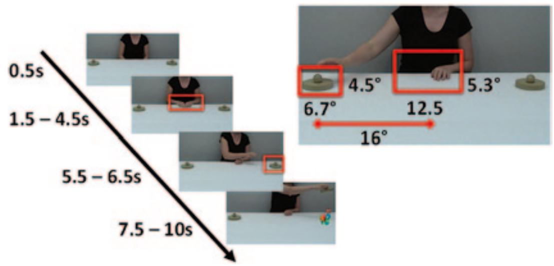

Fig. 2.5 *Sequence of actions appearing on each trial.* The hands continued to tap on the table until infants looked at them for 500 ms. Goal prediction was defined as the eyes entering the area of interest surrounding the lid before the hand touched the lid

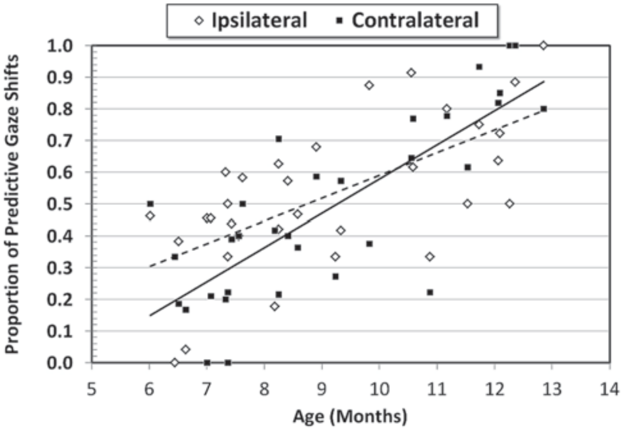

Fig. 2.6 *Mean gaze shift times from the hands to the lid.* Positive gaze shift times indicate that gaze anticipated the hand grasping the lid; negative gaze shift times indicate that gaze lagged behind the hand grasping the lid

it is specific to the type of movement (i.e., ipsilateral vs. contralateral reaches). Strictly speaking, some third variable could account for improvements in both the prediction and production of contralateral reaches, but it is difficult to imagine any variable aside from motor experience that might mediate differences in the development of goal prediction as a function of reach type.

2.4.6 Observation–Execution Matching of Nonhuman Actions

Thus far, we have reviewed evidence showing that action observation is linked to action understanding at the level of both movements and goals. One unresolved issue in the literature is whether the process responsible for linking the observation and execution of actions is limited to human actions, or whether it generalizes to nonhuman and mechanical actions. The majority of evidence with adults suggests that the observation of robotic or mechanical actions results in less activation of the motor system, and thus, at the very least a diminished neural, as well as behavioral, response (e.g., Kilner, Paulignan, & Blakemore, 2003; Press, Bird, Flach, & Heyes, 2005; Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004). This result is typically interpreted as supporting the hypothesis that an observation–execution matching system is limited to actions within the motor repertoire of the observer, or that the observer codes the action at the level of its intention, which does not exist in nonhuman agents (e.g., Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005; Teufel, Fletcher, & Davis, 2010).

According to either of these interpretations, infants should be unlikely to automatically activate a motor response when observing a nonhuman agent, such as a mechanical claw. Indeed, previous research by Woodward (1998) revealed that infants' understanding of a functional relation between a goal and an action was not generalized to situations involving either an inanimate rod or a mechanical claw. In spite of this finding, Gerson and Woodward (2012) reported that 7-month-old infants were able to identify the goal of an action performed by a claw-shaped tool after receiving some active experience using the tool to grasp objects. By contrast, they did not identify the goal after merely interacting with the tool or observing the experimenter use it to move objects. The authors concluded that it was necessary for infants to motorically experience these actions and compare them to observed actions for infants to understand the goal structure of the event. In this case, it seems reasonable to conjecture that observational learning was not sufficient, because the actions necessary for moving these tools were not yet incorporated within their motor repertoire. Still, there are exceptions to this conclusion suggesting that observation of claws without motor experience is sufficient to induce motor understanding (Gerson and Woodward, 2014; Hofer et al., 2005).

How can we reconcile these seemingly contradictory results? As we previously suggested, all types of observational learning are not the same and it is especially important to guide infants' attention with ostensive cues if they are to benefit from the modeled behavior (Boyer & Bertenthal, in press; Csibra, & Gergely, 2009). Boyer et al. (2011) offer some preliminary evidence for this prediction. They tested 9-month-old infants in the observational version of the A-not-B paradigm used by Longo and Bertenthal (2006), except that the experimenter was replaced by two mechanical claws that mimicked the actions of the experimenter in the object hiding experiment (see Fig. 2.7).

Three experiments were conducted with each successive experiment providing more claw experience before testing began. The first experiment provided infants with no claw experience before testing, and the results revealed that infants were just as likely to search in the correct, as opposed to, the incorrect location. At the beginning of the second experiment infants were familiarized with the experimenter and the claws by observing the experimenter handle the claws and other toys for approximately 2 min. During this familiarization phase, the experimenter used

Fig. 2.7 *Infant observing the mechanical claws grasp the toy (Experiment 1).* (Reprinted with permission from Boyer et al., 2011)

ostensive cues, including infant-directed speech and contingent responses, to attract infants' attention, but the results were no different than those reported in Experiment 1. At the beginning of the third experiment, infants observed the experimenter use the claws to retrieve toys that were beyond his reach for approximately 2 min. Once again, the experimenter engaged the infant with ostensive cues, but this time the intent was to direct attention not to the experimenter himself, but rather to the actions performed by the claw. Unlike the results from the first two experiments, a significant number of infants now searched incorrectly on the B trial. These results are significant for two reasons:

(1) Woodward and Gerson (2014) suggest that infants are capable of understanding the goal-directed actions of tools if they receive active experience with them. This experience enables infants to store the goal structure of the action so that a mapping can be formed between the observation of the tool and its motor representation. In the case of the claws, however, infants were unable to gain active experience because they were too large to manipulate, and also representing the object-directed goal would not bias them to search in the incorrect location because the goal was identical in both locations (i.e., retrieve the hidden object). Boyer et al. (2011) suggest that at least with regard to motor simulation, which is necessary for inducing the search error, it is not just the goal or the effect of the action, but rather the *means–end relation* that is critical for infants' action understanding. As a function of the familiarization phase, infants gained experience observing how the claws achieved the end result of retrieving the toys, not with a hand, but rather with a tool controlled by the hand. As a consequence of observing an association between the claw and the hand controlling it, infants were inclined to generalize this observed action to their stored representation of goal-directed reaching (cf. Boyer et al., 2011). Once infants were primed during this familiarization period, they were inclined to develop a response bias to the A-location during testing just as they had in the previous studies when observing a person hiding and finding the displaced object.

(2) Even though infants did not actively manipulate the claws, they appeared to learn from observing the experimenter. In this case, learning benefited from the experimenter not performing the same identical action repeatedly, but rather varying both the location of the toy and the hand used to retrieve it. Variation and selection from multiple examples is a well-established mechanism for facilitating learning (e.g., Bertenthal, 1999; Siegler, 1994). This variation is easy to overlook when comparing active to passive experience, but infants' are not yet well coordinated and thus virtually any action will vary in one or more details each time it is executed. Accordingly, infants are assured to receive some variable experience when performing actions themselves, but this will be less likely when modeled by an adult unless the variation is intentional. In addition, infants benefited from the experimenter structuring the situation, so that they could coordinate their attention to both the experimenter's face and his goal-directed actions. Infants tended to alternate their attention back and forth between the experimenter and the objects that were grasped by the claws.

> In other words, they engaged in joint attention, which we hypothesize significantly contributed to the likelihood of infants mapping the actions of the claw to their own reaching actions.

Although we can only speculate at this time, we hypothesize that another reason why observational learning leads to inconsistent results with regard to action understanding is that it is facilitated by joint attention, which is not controlled in these studies. In the next section, we discuss in more detail the processes by which joint attention develops and contributes to infants' understanding of a social partner's actions.

2.5 Coordination of Attention Between Infants and Their Social Partners

2.5.1 Attention to People and Objects

As previously discussed, infants begin to engage in triadic interactions involving joint attention and some shared understanding of mental states around 9–12 months of age. In order for them to develop this shared understanding, they must also learn to coordinate their attention to their social partner with their attention to objects. Although it is well established that this developmental transition occurs, little is known about how an early preference for faces gives way to a more distributed view of the social world that includes not only faces, but bodies and actions, as well as objects. In general, attention is the front-end of encoding and interpreting all stimulus information encountered in the environment, and thus it is essential for not only learning to recognize and discriminate faces, but the actions of people as well. How do infants decide where to look from moment-to-moment when confronted with not only a dyadic partner but also an assortment of objects, other people, and events in their optic arrays? Early on, infants' orienting to stimuli in the environment is primarily under exogenous stimulus-driven control, but over time they begin to also develop endogenous control over their attention (Johnson, 2011; Mundy & Jarrold, 2010). As such, they begin modulating their attention in response to the actions of others as well as the context. Indeed, this is exactly what is necessary for infants to follow the gaze direction of a social partner during shared attention. If infants could not modulate their attention, then they would simply continue to be guided by their bias for faces, but the development of joint attention suggests otherwise.

Although there has been considerable research investigating the social cognitive prerequisites for joint attention, such as shared intentions or common ground (Tomasello, 2008), much less is known about how, and when, infants begin to coordinate their social attention between faces, actions, and objects. One reason for the sparseness of relevant findings is that most studies obviate the need for infants choosing between different stimulus cues. As previously discussed, infants are typically presented with a specific sequence of events, such as an actor eliciting an infant's attention, and then looking or pointing in a specific direction followed by an object appearing in either that direction or the opposite direction; infants merely have to attend to the stimuli in the order they appear and not choose when, and what, to look at (e.g., Bertenthal et al., 2014; Daum et al., 2013). In more naturalistic situations, such as an infant interacting with a caregiver in a cluttered room among a set of objects over a more extended period of time, the caregiver might alternate between gazing at the child and the objects, and jointly playing with those objects or showing them to the child. The question then becomes, how much are infants' looking behaviors guided by attention to the face, or by attention to the actions of the caregiver, the orientation of her face, her body posture, or changes in her object-directed actions?

Recent advances in infants' eye-tracking research offer important opportunities for systematically investigating how infants distribute their attention to social and nonsocial stimuli. Most studies, however, still rely on presenting highly scripted and repetitive actions to infants in experimental paradigms involving a digital image, or movie, of a social partner looking or reaching toward an object following an ostensive cue, such as eye contact with the viewer (e.g., Senju & Csibra, 2008; Daum et al., 2013). Frank and colleagues (Frank, Vul, & Johnson, 2009; Frank, Vul, & Saxe, 2012) have made some important progress in studying infants' and toddlers' social attention to more naturalistic visual scenes. In one experiment, the visual fixations of infants and toddlers between 3 and 30 months of age were recorded while viewing short videos of objects, faces, children playing with toys, and complex social scenes involving more than one person (Frank et al., 2012). The youngest infants looked primarily at faces and eyes, but older infants and toddlers distributed their gaze more flexibly, and looked more at the mouth and also the hands, especially when the hands were engaged in actions on objects. Also, the distribution of fixations differed not only as a function of age, but as a function of specific actions. For example, older children, in particular, looked at the mouth more often when the actor was smiling or talking (even though there was no accompanying sound).

A more recent study by Elsabbagh et al. (2014) also studied infants' relative distribution of fixations to the eyes and mouth when viewing a social partner with eyes, mouth, or hands moving or expressing multiple communicative signals (e.g., peek-a-boo). Consistent with previous studies, infants between 7 and 15 months of age looked at the eyes more than the mouth, but this difference was contextually modulated such that when only the mouth moved infants looked more at the mouth than when only the eyes moved. Taken together, these few studies suggest that by sometime during the latter half of the first year infants' social attention is controlled by both stimulus-driven factors, such as eyes and faces, and more endogenous or goal-directed factors that can exert control of looking behavior.

2.5.2 Effects of Salience and Context on Attention

Recently, Boyer, Harding, and Bertenthal (2015) conducted an eye-tracking study to better understand how infants dynamically select and synchronize their focus of attention during ongoing social interactions with people and objects. This dynamic

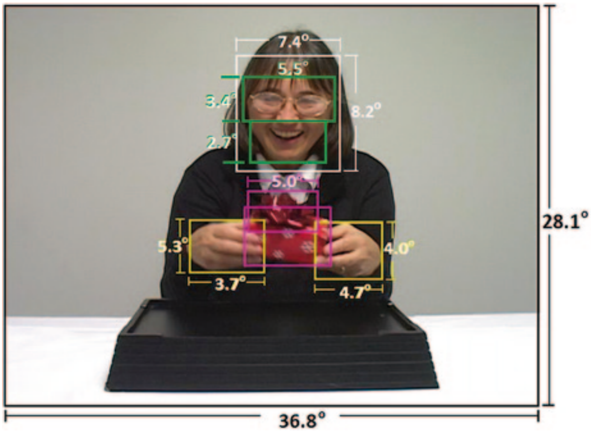

Fig. 2.8 *Screenshot from one of the stimulus videos with an overlay of the AOIs*. The numerical dimensions of each AOI correspond to their mean size based on all frames of the video

selection of where to look is a prerequisite for joint attention, and is facilitated by infants following their social partner's head orientation and eye gaze. From this experience they learn that during direct gaze there is an opportunity for eye contact and communication with the social partner, whereas during averted gaze there is an opportunity for joint attention toward another person or object (e.g., Johnson, 2006; Triesch et al., 2006). If, however, the social partner is waving her hands, or manipulating an object, while looking at the infant, the likelihood of the infant establishing eye contact with the social partner decreases. In typical social interactions, the cues for where to look will often compete and this is especially true for young infants outside the laboratory.

Unlike the studies conducted by Frank and colleagues (2009, 2012), the stimuli used by Boyer et al. (2015) were not movies of people or cartoon characters shown from a third-person perspective such that infants were simply watching a movie. Instead, these stimuli were created to show different actors socially engaged with the viewer from a first-person perspective. Although the stimuli were videos, they were designed to simulate naturalistic interactions that could occur between an adult and an infant. Each of 16 videos presented one of five female actors talking and demonstrating a sequence of simple actions, such as putting a shirt on a stuffed animal. Contrary to conventional wisdom, a few recent studies suggest that infants do not always look at the social partner's eyes or face during joint attention; instead, they sometimes focus on sharing attention to the same goal-directed actions (Deák, Krasno, Triesch, Lewis, & Sepeta, 2014; Franchak, Kretch, Soska, & Adolph, 2011; Yu & Smith, 2013). Thus, it was important to include not only people and their gestures but also object-directed actions. Three age groups were tested: 8-month-old infants, 12-month-old infants, and adults. Dynamic areas of interest (AOIs) were created around the faces, hands, and objects shown in each video in order to quantify the proportion of time that participants directed their attention to theoretically significant portions of the stimulus (see Fig. 2.8). Over the course of each video, participants' would continuously change their focus of attention from one AOI to another, but there was considerable consistency in how attention was dynamically allocated (Fig. 2.9).

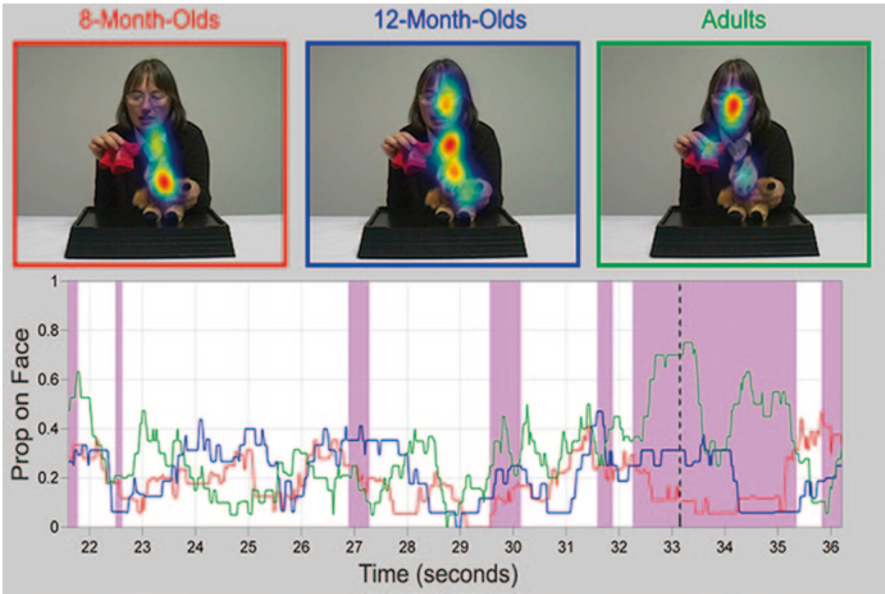

Fig. 2.9 *Top panels. Heat maps of the mean likelihood of looking at a specific location on one frame of one of the videos for each of the three age groups.* This frame occurred 33.2 s. after the video began. *Bottom panel. Proportion of participants in each age group looking at the face on each frame (red: 8-month-old infants; blue: 12-month-old infants; green: adults).* The shaded regions correspond to direct gaze by the actor, and the non-shaded regions correspond to object-directed gaze by the actor. The dashed vertical line corresponds to the time of the video frame depicted in the top panel

Overall, infants and adults showed similar patterns of looking at the stimulus information with greatest attention directed toward objects, followed by attention to faces and hands (Fig. 2.10). As such, this result contrasts with reports from many previous studies suggesting a face preference (e.g., Frank et al., 2012; Jones & Klin, 2013). It is very likely that these differences are at least partly attributable to variations in the stimuli, including whether or not actions were included, people were seen from either a first- or a third-person perspective, and eye gaze alternated between looking at the viewer and directing attention to other objects in the scene. This is but one of many reasons why simulating more natural viewing conditions is essential to a comprehensive study of social attention (see Nasiopoulos, Risko, & Kingstone, Chap. 5, this volume, for further discussion of this issue).

An important innovation of this study was to also assess how visual attention was contextually modulated. For example, both adults and 12-month-old infants looked more at faces when actors' gaze was directed at the viewer, and looked more at objects when actors' gaze was directed toward the objects (see Fig. 2.11). Likewise, all three age groups looked more at objects when they were manipulated by the actor than when they were not held, but only the adults looked more at faces when the objects were not held. Taken together, these results suggest that 8- to 12-month-old

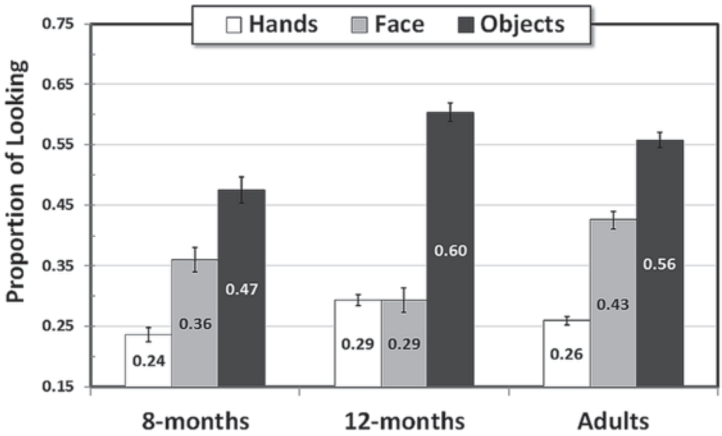

Fig. 2.10 *Mean proportions of each trial participants directed attention to the hands, face, and objects as a function of age.* Error bars represent +/− standard error of the mean

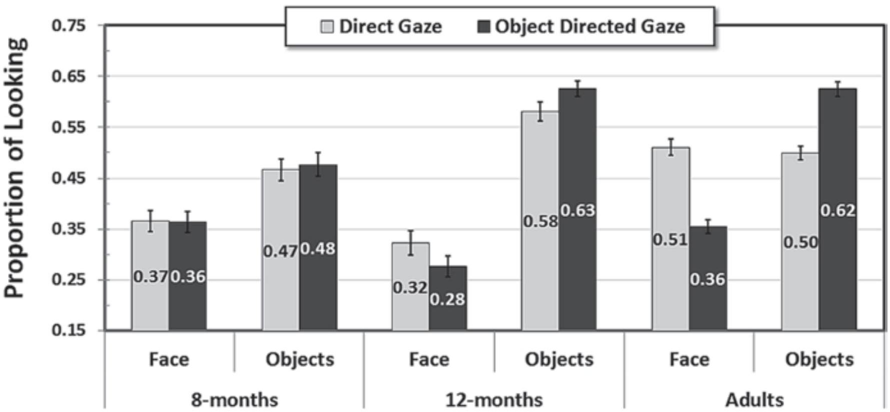

Fig. 2.11 *Mean proportion of each trial participants directed attention to the face and objects as a function of age and actors' direct versus object-directed gaze.* Error bars represent +/– standard error of the mean

infants' attention to the social world is not only mediated by the meaningfulness of faces and objects, but also modulated by their knowledge of social cues and actions. Through repetitive interactions with their caregivers and other social partners, infants are tutored by their perceptual experiences to coordinate their attention in response to social cues and actions in order to communicate as well as to learn.

This transition does not happen all at once but rather gradually. It seems reasonable to hypothesize that for very young infants' attention is captured by the most salient stimulus in the visual environment, which is typically a face, and they continue to focus on that same stimulus until a new salient stimulus appears, or they habituate and then orient elsewhere. By contrast, the first signs of volitional attention appear around 3–4 months of age, when infants begin to display prospective control of saccades (Johnson, 2011). Once intentional control of visual attention emerges, infants' processing of contextual information begins to influence where they choose to attend. This contextual information will include social cues (e.g., gaze following, pointing) and goal-directed actions, which infants are beginning to learn about by 5–6 months of age (Rohlfing et al., 2012; Woodward, 1998). Although infants reveal some precocious understanding of these behaviors at early ages, we suggest that there is an important distinction between infants developing some representation of a person's goals or intentions, and responding to those perceived goals or intentions in a meaningful way (cf. Klin, Jones, Schultz, & Volkmar, 2003). In our study, it is not until sometime between 8 and 12 months of age that infants are prepared to modulate their attention in response to the actor's social cues.

2.5.3 Reciprocity Between Coordination of Attention and Social Understanding

Some theorists assume that the development of joint attention relies primarily on the development of social–cognitive knowledge, which enables infants to appreciate the intentions of others (e.g., Carpenter et al., 1998; Woodward, 2009). Unless one assumes that this social–cognitive knowledge is encapsulated as an innate module, it is necessary to explain how this knowledge is learned. Infants' visual attention biases them to look at people and their actions, and these results suggest that their attention becomes better coordinated with the actions of a social partner over time. These changes in the coordination of attention occur during the same period of time that infants begin to develop an understanding of others' intentions, which thus blurs the direction of effects. This is not necessarily an unwelcome conclusion, because it is quite conceivable that the development of joint attention represents a dynamic and reciprocal relation between the development of infants' social–cognitive knowledge and their attentional foraging of social interactions.

As such, the distribution of attention by the 8-month-old infants may have represented a phase where they were simply not yet aware of the social cues, and thus their responses did not differ as a function of these cues. This interpretation is, however, not likely to be entirely correct given what we know about infants' understanding of social cues (e.g., Bertenthal et al., 2014; Hood et al., 1998). Alternatively, these infants were still *learning* how best to distribute their attention during these bouts of joint attention with a social partner in which they were communicating face-to-face as well as jointly viewing one or more objects. During this learning phase, 8-month-old infants would have the opportunity to learn more about the social–communicative actions of others by mirroring them and observing their partner's responses (Bertenthal & Longo, 2008; Shepherd & Cappuccio, 2012; Woodward & Gerson, 2014). By contrast, 12-month-old infants were already able to represent the very basic intentions of the actors (e.g., Tomasello, 2008), and thus were no longer just exploring how to coordinate their attention with that of the actors. The function of attention for these older infants was more akin to a *decision* process in which their goal was to select the relevant information in order to decide where to look next.

2.6 Summary and Future Directions

2.6.1 Challenges to Studying Social Attention

Social attention does not develop all at once, but infants make rapid progress during their first year. We now know a good deal about what infants attend to, but our understanding of how this attention develops is still piecemeal and fragmentary. Early on, neonates show preferences for very simple face-like stimuli, or at least featural relations correlated with faces. Johnson and Morton (1991) suggest that these early stimulus-driven preferences predispose infants to learn quickly about the identification and discrimination of faces. Theorists who advocate for associative learning might predict that the frequency and duration of exposure to faces is responsible for what is learned, but experience per se is not sufficient for explaining the sequence or rate of learning. The "devil is in the details," which as of now are still very murky. For example, it is clear that the processes available for face perception improve with a shift from subcortical to cortical processing around 2 months of age (Johnson, 2011), and that the hedonic value of faces reinforces infants to continue looking at these stimuli (Triesch et al., 2006). Although we also know that infants begin categorizing faces by 3 months of age (Quinn, 2002), the specific learning mechanisms responsible for these accomplishments, or for the perceptual narrowing of the face schema to the same species (Pascalis et al., 2002), remain elusive.

One of the biggest challenges to identifying the processes responsible for the development of social attention is that it is a moving target and these processes continue to change with age and experience. If we focus on just the first few months of development, this question becomes at least a little more tractable, because it is assumed that attention is primarily, if not exclusively, driven by the stimulus, and thus predicting where infants will look is mostly a function of determining the salience of the stimulus. Yet, even this issue is difficult to resolve, because it remains controversial as to whether salience should be defined in terms of physical conspicuity, biological survival value, social meaning, or affective resonance (Gottlieb & Balan, 2010). Once infants begin to control the direction of their orienting through endogenous processes (i.e., goal-driven attention), the complexity of the problem explodes, because infants are then able to decide where to look next based on not only the salience of the stimulus but also their intrinsic or extrinsic goals, which are shaped by their social understanding and prior experiences.

In this chapter, we have focused on the development of joint attention to illustrate how stimulus salience, action understanding, and contextual modulation of attention contribute to its development. Each of these processes will be discussed in turn.

2.6.2 Stimulus Salience

As we discussed, infants begin to match or coordinate their attention to that of a social partner by 3–4 months of age when following eye gaze or the direction of a pointing gesture. It is possible for infants to accomplish this act without any understanding of the others' goals or intentions. In essence, infants learn to shift their attention in response to a deictic cue, which occurs because it is associated with movement in the same direction as the target (Rohlfing et al., 2012). The association with movement facilitates this shift because infants are capable of tracking objects by this age (Kellman & Arterberry, 1998), which will bias them to continue looking in the same direction. Presumably, the targets of these social cues are often rewarding and thus through contingency learning, or more formally, reinforcement learning (Triesch et al., 2006), they learn to shift their attention toward new objects or events.

As an aside, most of the evidence supporting this development is based on a spatial cueing paradigm, yet paradoxically this paradigm may not be well designed for studying social attention (cf. Birmingham & Kingstone, 2009). Recall that none of the gaze-cueing studies compared infants' responses to social and nonsocial cues, and the one study testing point following that compared these cues did not report an advantage for social over nonsocial pointing until 6 months of age. Although this failure might have been attributable to limitations in perceptual discrimination at 4 months of age, the evidence for a significant preference to the pointing hand versus the foil refutes this possibility. Instead, we suggest that the problem lies with the paradigm, because it tends to measure stimuli on a dimension in which the stimulus cues all share considerable similarity (i.e., communicating a specific direction; Gibson & Kingstone, 2006).

In the natural visual environment, it is first necessary to scan the visual array and select a stimulus cue, such as a face or eyes, before shifting attention in the direction of that cue. Some recent research suggests that it is during the selection phase that a social stimulus exerts its greatest advantage (Birmingham & Kingstone, 2009). If the stimulus cue is preselected as occurs in a spatial cueing paradigm, then the likelihood of observing a difference between processing social and nonsocial cues is reduced. Conceivably, this is the reason that so many adult spatial cueing studies fail to show a response time difference between gaze and arrow cues (e.g, Hommel, Pratt, Colzato, and Godijn, 2001; Kuhn & Kingstone, 2009; Tipples, 2002). Similarly, this paradigm is likely to underestimate differences in orienting to social and nonsocial stimuli in infants if these differences are partly attributable to selective attention. Indeed, this is very likely given that infants showed a strong preference for the pointing hand over the pseudo-hand and the arrow (Bertenthal et al., 2014). There is also evidence from brain studies that infants are biased to selectively attend to social stimuli, because specialized areas in the brain sensitive to these stimuli are already functional by 4 months of age (Grossman & Farroni, 2009; Johnson, 2011). If infants were tested in more naturalistic situations, we predict that the observed differences in responding to social and nonsocial stimuli would have been greater, because these differences would have been amplified by the greater likelihood of selectively attending to the social versus nonsocial stimuli.

2.6.3 Action Understanding

Once infants begin following the social cues of their partners, they have the opportunity for extensive practice and tutelage from observation. By observing others' orienting behaviors that they themselves are capable of performing, it is conceivable that infants will begin matching their own actions to those observed, and this will facilitate their understanding of the goals or intentions of the social partner. It is important to emphasize that this is a very gradual process, and seems at least somewhat dependent on motor experience. This is the reason that infants may engage in point following by 4 months of age, but do not demonstrate that they understand the others' intention in pointing until close to a year of age, after they themselves are capable of pointing (e.g., Brune & Woodward, 2007). Throughout the day during play and feeding with their caregivers, infants will have the opportunity to observe and mimic not only deictic cues but also other goal-directed actions, such as reaching and manipulating objects. By mirroring these actions (i.e., mapping observed actions to motor representations), infants will learn about the goals and intentions of actions performed in their field of view.

Although infants will have the opportunity to observe goal-directed actions from birth, it is not until 5–6 months of age that they begin to understand the relation between the action and the goal. There is now some very convincing research showing that this action understanding is related to motor experience (Woodward & Gerson, 2014), but there seems to be a tendency to dismiss observational learning too easily because of a failure to recognize the importance of social communicative cues and contingent feedback during these interactions. As we emphasized throughout this review, there is a reciprocal relation between social understanding and social attention, and it is therefore critical to consider the contributions of both when studying social cognition. More generally, it is rarely the case that two behaviors that develop, such as social attention and social understanding, will follow a sequential developmental sequence, because development is dynamic and nonlinear, and thus virtually all related behaviors interact as they change and become more complex (Thelen & Smith, 2008).

2.6.4 Contextual Modulation

Endogenous orienting of attention is akin to decision-making (Gottlieb & Balan, 2010), because the observer needs to process the current perceptual information and decide where to direct attention next. During joint attention, infants are expected to follow the gaze or pointing direction of their partner because they have learned that this response is often rewarding (e.g., Triesch et al., 2006). In most natural situations, however, the decision as to where to look next is not as straightforward. Infants observe multiple cues including not only gaze and pointing, but also facial expression, speech, prosody, body orientation, manual actions, etc. All of these cues are potentially informative and are selected based on prior knowledge as well as current goals (Boyer et al., 2015). If all of these cues predict the same response, then the outcome is clear, but this is rarely the case. As we discussed in the preceding section, the likelihood of infants responding to the actor's face or goal-directed actions is probabilistic and depends on how attention is modulated by other cues, such as head orientation and eye gaze or the manual actions that are performed. One important implication from this evidence is that it is not sufficient to record where an infant looks, because the reason for looking in a specific direction is often a function of the child's social understanding, which encompasses not only the current focus of attention but also contextual information including social communicative cues as well as goal-directed actions.

When do infants begin to modulate their attention in response to contextual cues? The findings from Boyer et al. (2015) suggest some responsiveness to manual actions by 8 months of age, but it was not until 12 months that infants showed systematic responses to multiple cues including direction of eye gaze. At first blush, this latter finding may seem at odds with the evidence suggesting the existence of gaze following by 3–4 months of age. Yet, the situations are very different, because gaze following at these young ages was observed only when the stimulus information was limited to eye gaze, and even this cue was subsequently removed in order to ensure that infants would shift their attention to the target. By contrast, infants viewing movies of actors engaged in joint attention with them as well as objects were confronted with a much more complex task that would be responded to differently depending on their social understanding. As we previously discussed, this social understanding was tutored by infants mirroring the behaviors performed by their caregivers, as well as being mimicked by them (e.g., Boyer et al., 2015; Bigelow & Power, 2014). This exploratory stage of joint attention also enabled them to begin identifying correlations between different cues so that eventually their direction of attention was not only a function of the salience or meaningfulness of specific AOIs (i.e., face, hands, objects) but also a function of informative contextual cues (e.g., eye gaze, goal-directed actions, facial expressions). Thus far, the research by Boyer et al. (2015) is restricted to measuring only one contextual cue at a time, but ongoing work is using information theoretic measures, such as Shannon entropy and cross-recurrence plots, to assess the predictability of the response from multiple cues simultaneously.

2.6.5 Conclusions

In this chapter, we have focused on social attention as a dynamic process that involves the responses of observers to actions (eye gaze, facial expressions, head and body orientation, goal-directed actions) performed by others. We have emphasized that social attention is not a monolithic process, and that it develops gradually throughout the first year in association with perceptual development, action understanding, and coordination of joint actions. Our primary goal was to show that social attention is not merely a product of development, but it is a process as well.

In essence, social attention is recast from the role of primarily informing researchers about where and how long infants look at social cues to how they are looking and how their attention will directly contribute to social learning. As infants' motor repertoire develops and they are better able to direct their attention to informative social cues, their understanding of others' actions continues to develop. This is the reason that there is a mutual and reciprocal relation between social attention and social understanding. The development of this relation is complex and involves the interaction of multiple factors, some of which were discussed in this chapter. An important goal for the future is to continue to explore how social attention is both a measure of social cognition and a mediator of its development.

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The Many Faces of Social Attention
Behavioral and Neural Measures
Puce, A.; Bertenthal, B.I. (Eds.)
2015, X, 249 p. 31 illus., 18 illus. in color., Hardcover
ISBN: 978-3-319-21367-5