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Detecting agents

Susan C. Johnson

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THE ROYAL SOCIETY

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Detecting agents

Susan C. Johnson

Department of Psychology, Jordan Hall, Building 420, Stanford University, Stanford, CA 94305, USA
(*scj@psych.stanford.edu*)

This paper reviews a recent set of behavioural studies that examine the scope and nature of the representational system underlying theory-of-mind development. Studies with typically developing infants, adults and children with autism all converge on the claim that there is a specialized input system that uses not only morphological cues, but also behavioural cues to categorize novel objects as agents. Evidence is reviewed in which 12- to 15-month-old infants treat certain non-human objects as if they have perceptual/attentional abilities, communicative abilities and goal-directed behaviour. They will follow the attentional orientation of an amorphously shaped novel object if it interacts contingently with them or with another person. They also seem to use a novel object's environmentally directed behaviour to determine its perceptual/attentional orientation and object-oriented goals. Results from adults and children with autism are strikingly similar, despite adults' contradictory beliefs about the objects in question and the failure of children with autism to ultimately develop more advanced theory-of-mind reasoning. The implications for a general theory-of-mind development are discussed.

Keywords: agency; infancy; self-propelled motion; intentionality; theory of mind; autism

1. MENTALISM IN INFANCY: PEOPLE AS AGENTS

One commonly held position in the study of infant social cognition is that:

(i) infants distinguish between people and non-people; and
(ii) infants' earliest understanding of other minds maps directly onto this distinction.

Although the first claim has been well-documented, the second has been largely taken for granted (see Legerstee 1992, 1994; Wellman 1993; Meltzoff 1995; Poulin-Dubois 1999; Johnson 2000 for related reviews). This second point can be broken down into two related questions: when do children first attribute mental states to others and when they do, whom do they attribute mental states to? The answer to these questions may well provide insight into the nature of the representational systems underlying mentalistic reasoning. This paper will review a line of research designed to do just that.

Mental states are unobservable constructs that must be inferred by observers rather than perceived directly. They are distinguished from other sorts of unobservables or internal states by the specific kind of relationship they hold with the world. That is, mental states are *directed at* the world; they are *about* things (Lycan 1999). Other commonplace, commonsense unobservables (e.g. life, essences, atoms, etc.), although presumed by lay thinkers to exist in the world, are not presumed to be about the world. The ability to construe ourselves and others as agents with mental states such as perceptions, attention, desires and beliefs is critical. With this mentalizing ability we can communicate referentially, predict and explain others' behaviours, and manipulate both our own and others' mental states for the purposes of complex problem-solving and learning, not to mention deception. Mentalizing is so critical in fact, that its absence is thought by some to be a central cause of autism (Baron-Cohen *et al.* 1993; Baron-Cohen 1995).

Garnering evidence sufficient to demonstrate mentalizing is difficult, however. Many behaviours that could potentially serve as indices of mentalizing (e.g. gaze-following, pointing, goal imitation) can typically be interpreted in both mentalistic and non-mentalistic ways. Non-mentalistic explanations based on signal releasers, attentional enhancement and object affordances have all been proposed to explain the variety of behaviours produced by prelinguistic infants (Butterworth & Jarrett 1991; Gerwitz & Pelaez-Nogueras 1992; Moore & Corkum 1994; Hood *et al.* 1998). The interpretative problems are particularly acute for the attribution of mental states that are correlated with reality (e.g. perception or goals) and can thus be mimicked by conditioned or reality-driven behaviours (Dennett 1978).

Although the point is well taken, it does not mean that infants do not attribute mental states to agents; only that sufficient evidence for such a claim is difficult to generate. It does mean, however, that as long as the agents used to test infants' competency are highly familiar to infants, as are people, non-mentalistic explanations are difficult, if not impossible, to rule out. Much of the work in this area has none the less presupposed the role of people in infants' attributions of mental states. Certainly, between the ages of 9 and 18 months, infants have begun to interact with people as though they believe people have minds. They

One contribution of 15 to a Theme Issue 'Decoding, imitating and influencing the actions of others: the mechanisms of social interaction'.

produce communicative gestures such as points, requests and displays for other people (see Bates *et al.* 1975; Leung & Rheingold 1981; Bretherton *et al.* 1981; Butterworth & Grover 1988); they follow adults' gazes (Scaife & Bruner 1975; Lempers 1979; Butterworth & Jarrett 1991; D'Entremont *et al.* 1997; Corkum & Moore 1998) and they guide their own behaviour towards objects on the basis of other people's emotional and goal-directed behaviour towards those objects (Meltzoff 1995; Baldwin & Moses 1996; Repacholi & Gopnik 1997; Woodward 1998; Moses *et al.* 2001; see also Johnson 2000, for a recent review.)

The emphasis on humans as the target of infants' mentalizing is not accidental. A great deal of evidence has accumulated showing that very young infants can and do *distinguish* between humans and non-humans. At birth, infants preferentially track the movement of faces (Morton & Johnson 1991) and imitate the facial and hand gestures of people (Meltzoff & Moore 1977, 1983; Field *et al.* 1982) but not inanimate objects (Legerstee 1991). From 3 months to a year, infants smile, vocalize and gesture more in the presence of people than inanimate objects, while visually fixating and reaching more towards animals or inanimate objects, even when the inanimate objects resemble people in very salient ways both perceptually and behaviourally such as dolls, interactive robots and animals (see Legerstee *et al.* 1987; Ellsworth *et al.* 1993; Ricard & Allard 1993; Legerstee 1994, 1997; Poulin-Dubois *et al.* 1996; but see Frye *et al.* 1983 for contradictory results).

The ability to *discriminate* people from non-people, however, is no more sufficient evidence of mentalizing abilities than any of those described in the previous paragraph. It is possible that person discrimination could develop in support of important social and cognitive processes that are independent of mental state attributions (e.g. attachment and/or observational learning). Neither is person discrimination logically necessary for mentalizing abilities. That is, object recognition processes for identifying mentalistic agents need not be isomorphic with the processes for identifying people.

Given these two concerns:

(i) the problem of interpreting infants' behaviour in the context of highly familiar agents like people; and
(ii) the still underspecified function of the person/non-person distinction in infancy, it may be time to look more closely at infants' interpretation of non-humans.

It is particularly important to do so using measures that are closely associated with mentalizing abilities, such as communicative behaviours, joint attention behaviours, and so on.

In fact, several largely untested theoretical proposals have been offered about the cues that lay thinkers may use to identify mentalistic agents, human or otherwise. The features proposed fall into several overlapping classes: morphological features such as faces and eyes (Carey & Spelke 1994, 1996; Baron-Cohen 1995); asymmetry along one axis (Premack 1990, 1991; Baron-Cohen 1995); non-rigid transformation (Gibson *et al.* 1978); self-propulsion (Premack 1990, 1991; Leslie 1994, 1995; Baron-Cohen 1995); and the ability to engage in contingent and reciprocal interactions with other agents (Premack 1990, 1991; Spelke *et al.* 1995).

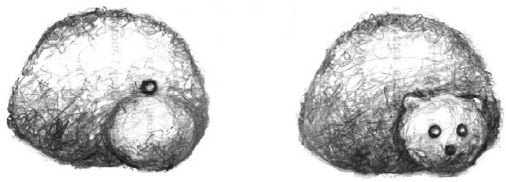

Figure 1. The novel object from Johnson *et al.* (1998). Both versions could make noises and flash an internal light.

The remainder of this paper will review work done by this author and colleagues on the role of these cues in eliciting mentalistic interpretations in both infants and adults. Initial work focused on the relationship between the infant's agent category and the infant's person category. More recent work has begun to test the limits on exactly what sorts of non-human objects infants are willing to attribute mental states to and the sorts of assumptions infants seem to make when doing so. Additional work examining the parallels between infant and adult attributions and their implications will be discussed. Finally, some preliminary results from autism will be discussed.

2. THE ATTRIBUTION OF PERCEPTION/ATTENTION TO NON-HUMAN AGENTS: MORPHOLOGICAL AND BEHAVIOURAL CUES

Johnson *et al.* (1998) was the first study of this series to examine whether any of the putative cues of agency would elicit mentalistic attributions in infants. To do this we created a small novel object that could be introduced to infants as the actor in a standard gaze-following method (Scaife & Bruner 1975). The object embodied many of the proposed cues for mentalistic agents, without being person-like. The size of a small beach ball, it was made of natural-looking fuzzy brown fur and had a naturalistic shape that was symmetrical along only one axis with a small cone-shaped bulge at one end (see figure 1). It was designed to vary in two dimensions: the presence or absence of facial features and the quality of its behaviour—specifically, whether or not its behaviour was contingently interactive with the infant or not. Its 'behaviour' was generated via a small remote-controlled beeper and incandescent light hidden inside it. Thus, it was possible to control the object from a hidden vantage point such that when the infant babbled, the object beeped back and when the infant moved, the internal light flashed in response.

Infants received a brief (60 s) familiarization period in which either the object reacted contingently to the infant's own behaviour, or the infant saw equivalent amounts of apparently self-generated beeping and flashing, but in a sequence that was random with the infant's own behaviour. After this familiarization, the object made a final attention-grabbing beep and turned to orient itself towards one of two targets placed on either edge of the setup (see figure 2). Infants were found to follow the orientation of the object by shifting their own attention (as indexed by eye movements) in the same direction as the object's turn significantly more often than in the opposite direction in three out of the four familiarization

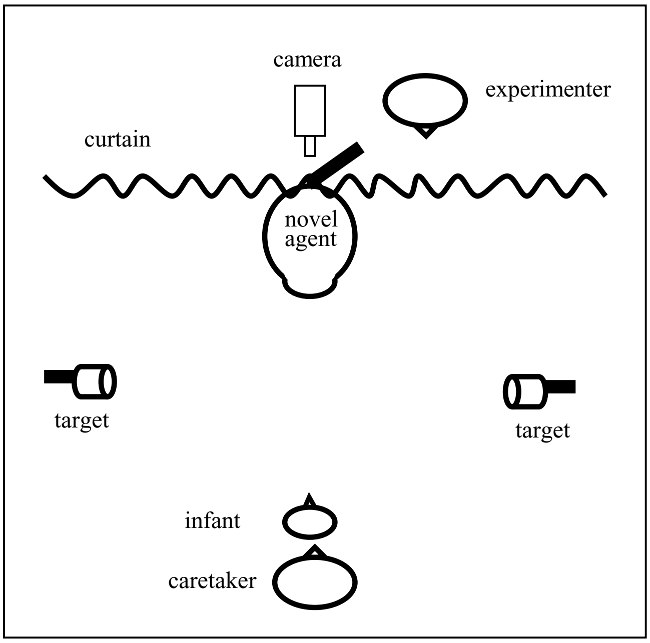

Figure 2. The setup from Johnson *et al.* (1998).

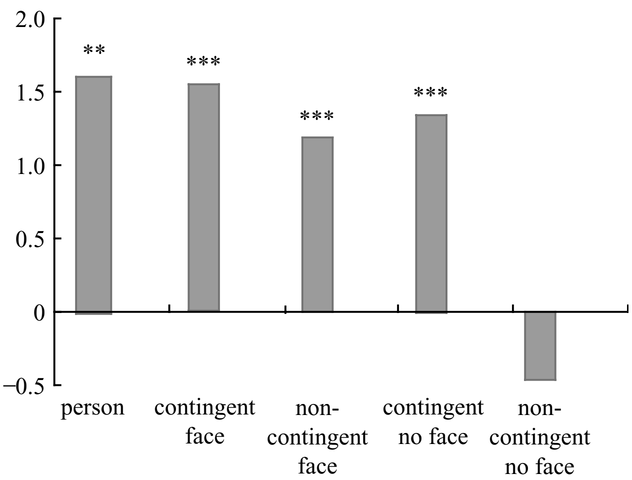

Figure 3. Data from Johnson *et al.* (1998). The score on the *y*-axis equals the total number of looks in the predicted direction minus the total number of looks in the unpredicted direction. $^{**}p < 0.01$, $^{***}p < 0.005$.

conditions; if the object had a face; if, when the infant babbled or moved, the object beeped back and flashed lights; or, both of these characteristics together (see figure 3).

Importantly, the object in the non-contingent, faceless condition embodied the same shape and movement cues as it did in the other conditions, but infants showed no reliable sign of following its orientation. This finding rules out the possibility that very general, perceptual information triggered shifts in the infants' attention without regard to the object's identity.

Finally, a comparison condition with unfamiliar adults taking the place of the object indicated that infants were no more likely to follow the gaze of a contingently interacting person than a contingently interacting fuzzy brown object with a face. Thus, these results seem to show that infants use relatively selective cues to decide when an object does or does not have a mind to perceive or attend with, specifically the presence of a face, or the propensity to interact contingently.

Taken alone, these findings might be interpreted as a generalization of previously conditioned behaviour from people to other objects that share some relevant but non-mentalistically interpreted feature such as eyes or interactive behaviour (though, interestingly, not self-generated behaviour). Why infants would generalize on some dimensions (i.e. interaction), but not others (i.e. self-movement) would then become an important question that a non-mentalistic account would have to address. None the less, as previously discussed, non-mentalistic accounts are difficult to rule out entirely.

3. THE ATTRIBUTION OF GOALS TO NON-HUMAN AGENTS: MORPHOLOGICAL AND BEHAVIOURAL CUES

There is one prediction that non-mentalistic accounts of individual behaviours give rise to that is not made by the mentalism account. Under non-mentalistic accounts, the scope of the putative agent category should vary across different behavioural contexts (e.g. attentional following, communication, imitation). For instance, a conditioning account of attentional following would not predict that the same set of object features would elicit both headturns in attentional following contexts and object manipulation in imitation contexts. Similarly, when behavioural contexts differ, signal-releaser accounts should predict different behavioural responses based on the existence of independent, evolutionarily specified mechanisms.

Conversely, converging (putative) attributions of agency to the same class of novel entities across a variety of diverse behaviours and contexts would indicate a common underlying representation. This would be evidence against disparate non-mentalistic interpretations. It is therefore all the more important to re-examine the person/non-person distinction in infancy, using as wide a variety of candidate mentalizing behaviours as possible.

With this in mind, Johnson *et al.* (2001) adapted two additional behavioural methods in such a way that infants could be introduced to a novel, contingently interacting agent and then given the opportunity to:

(i) re-enact the agent's unseen goals (Meltzoff 1995); and
(ii) interact communicatively with the agent by directing greetings, object requests and object displays at the agent.

In the method of Meltzoff (1995), 18-month-old infants were shown to re-enact the object-related goals of human actors (e.g. dropping a string of beads into a cup). When a human actor tried but failed to accomplish his goal, 18-month-old infants re-enacted the *inferred, unseen goal* rather than the spatio-temporally witnessed event. Meltzoff (1995) argued that the infants' performance could not be motivated purely by the spatio-temporal information in the action itself. In a condition in which the human actor was replaced by a mechanical set of pincers performing the same spatio-temporal actions, infants failed to re-enact any unseen actions. Meltzoff (1995) attributed this differential behaviour to an early naive psychology, based on and restricted to the infants' knowledge of people.

Johnson *et al.* (2001) challenged the extent to which infants, in fact, restrict their attribution of goals to human actors. We reasoned that unlike the novel object used in the gaze-following study of Johnson *et al.* (1998), the mechanical pincers of Meltzoff (1995) failed to embody any of the characteristics thought to imply a mind, and certainly had neither a face nor the ability to engage in contingent interactions. Therefore, we replicated the design and procedure of Meltzoff (1995), replacing the human actor with an animated stuffed orangutan that had a face and hands, the ability to move on its own, and the ability to interact contingently with the infant.

At 15 months of age, the infants tested in this study were somewhat younger than those tested by Meltzoff. None the less, the results revealed the same patterns seen in the original re-enactment method of Meltzoff (1995). Not only were infants able to reproduce the same literal outcomes of a series of actions produced by a non-human agent on objects (52% of the time), they were also able to produce the same target outcomes even when the agent tried but failed to produce them itself (37%). Both of the experimental conditions produced more target actions than infants produced spontaneously (only 10% of the time). As argued by Meltzoff (1995), this pattern indicates that the infants interpreted the agent's actions in terms of the agent's goals, rather than the spatio-temporal characteristics of the movements themselves, thus confirming the prediction that infants attribute goals (and mentalism) more broadly than previously thought.

4. THE ATTRIBUTION OF COMMUNICATION TO NON-HUMAN AGENTS: MORPHOLOGICAL AND BEHAVIOURAL CUES

In Johnson *et al.* (2001) we reasoned that if imitation of goals reflects an interpretation of the orangutan as an agent, that interpretation might be manifested in other ways as well. Communicative gestures such as showing, requesting and waving are all behaviours reflecting putative mentalistic attributions of agents. Informal coding of the infants in the goal re-enactment study revealed that most infants in all three conditions directed some sort of social/communicative behaviour at the agent at least once, including waving, showing or giving objects, requesting objects or alternating attention between the agent's face and a toy.

We ran a further study to rule out the possibility that the infants were simply taking their cues from the experimenter either by imitating the experimenter's gestures directly or by more generally imitating the experimenter's stance toward the agent. To do this, we built another novel object out of a common table lamp that was matched to the orangutan as closely as possible for visual interest without actually having any intrinsically agentive features of its own. It had comparable shape, colour patterns and moving parts. The experimenter then deliberately tried to induce in the infant a mentalistic stance towards the lamp on the basis of the experimenter's behaviour alone. The experimenter talked to the lamp, called it by name ('Bob'), and invited infants to communicate with the lamp by giving and requesting objects. Despite these direct attempts to induce the mentalistic stance infants were quite reluctant to treat it as an agent themselves. Though they waved to the orangutan, showed it objects, offered it objects, requested objects from it and actually withdrew physically from the orangutan, these behaviours were rarely used with the lamp.

5. PRELIMINARY SUMMARY

These three distinct infant behaviours, attentional following, imitation/goal-re-enactment and communicative gestures, have traditionally been thought to be the unique province of infant–adult interactions. These data now show that each can be elicited by non-human objects if those objects look or behave as agents themselves. The remainder of this paper will review two distinct lines of work that follow on from these original findings. The first addresses how the changes or lack of changes in these attribution patterns over development can inform our understanding of the representational systems involved. The second tests the power of behaviour alone to elicit mentalistic attributions from infants in the absence of supporting morphological cues. I will then conclude with some preliminary work on autism.

6. THE REVISABILITY OF THE AGENT CATEGORY

Some theorists (Fodor 1983; Leslie 1994, 1995; Baron-Cohen 1995; Carey & Spelke 1996; Johnson 2000; Scholl & Tremoulet 2000) have suggested that the selective use of low-level spatio-temporal information of the sort epitomized in temporally contingent interactions and facial configurations is characteristic of 'hardwired' object recognition processes. In addition, there is ample evidence now that infants can detect both faces and contingency information within the first weeks of life, while experience is still quite limited (faces: Morton & Johnson 1991; Slater *et al.* 2000; Slater & Quinn 2001; contingency: Watson 1972, 1979; Rovee-Collier *et al.* 1989).

One consequence of hardwired processes is incorrigibility in the face of counter-evidence, both over time developmentally and in real-time processing as seen in the case of familiar perceptual illusions. Illusions, such as the Mueller-Lyer illusion in which two lines of objectively equal length are made to look subjectively unequal by adding either inverted or everted arrows to their ends, are found throughout the processes responsible for the detection of 3D physical objects (Rock 1983). For real illusions, no amount of counter-evidence or insight into the reality of the situation will eliminate the perception.

Conversely, revisability is considered a characteristic of constructed concepts (Gopnik & Wellman 1994; Carey & Spelke 1996; Gopnik & Meltzoff 1997). Consider for instance, whether markings on a piece of paper are recognized as art. The answer can vary from culture to culture, generation to generation, person to person, and most importantly for present purposes, even over time within the same person. There appear to be no universal, hardwired 'art recognition' processes that yield the same output for all viewers regardless of past experience or beliefs.

This distinction between incorrigible and revisable representational systems and the resulting potential for illusions indicates a possible point of leverage into processes underlying infants' responses to the novel agent of Johnson *et al.* (1998). Even in its most animated states, the novel agent presented ample evidence *against* a categorization as an agent. To an adult, it would clearly be an artefact made of synthetic materials with an electromechanical noise generator and mechanically driven movement. If, despite this obvious counter-evidence, it elicited a psychological interpretation in adults, the argument that agent recognition is grounded in a hardwired system would be supported. Furthermore, this would indicate that the system is functional by at least 12 months as reflected in the infants' behaviour in Johnson *et al.* (1998).

Empirical evidence indicates that adults do experience illusions of mentalistic agency based on certain types of movement cue (e.g. the work of Heider & Simmel (1944)). Less work has been done on the role of contingent interactivity in adults' mentalistic attributions. Bassili (1976) showed adults 2D animations similar to those of Heider & Simmel (1944), except that temporal contingency and directional information were both carefully manipulated. He found that adults were sensitive to both types of information when interpreting the behaviour of unknown objects. Interestingly, participants seemed to use an object's contingent behaviour to categorize it as intentional and the direction of its movement to identify the content of its intention (i.e. its goal).

Given these considerations—the existence of hardwired object recognition processes in general and the probable existence of an 'illusion of psychological agency' in adulthood—whether the features that elicit attentional following in infants are themselves part of a dedicated system for recognizing agents bears consideration. If so, they should elicit parallel attributions in adults, despite adults' undeniable *beliefs* to the contrary. The results by Bassili (1976) suggest that they would, but given the considerable differences in stimuli and methods between the infant and adult work, additional studies seem merited.

S. C. Johnson (unpublished data) presented adults with a series of studies based on the attentional-following studies with infants described in Johnson *et al.* (1998). Adults were introduced to the same novel object under the same conditions—whether it had facial features and whether it interacted contingently to another agent. The proven verbal method used in the work of Heider & Simmel (1944) was adopted, rather than attentional following owing to the seeming potential for conscious, overt suppression of voluntary eye movements by adults. Participants' implicit impressions of the objects would be expressed in their verbal descriptions, which could then be coded for the use of mentalistic language.

The parallels between the adults' attributions and those found previously with infants were striking. Adults used mentalistic language to describe the behaviour of the object in just those conditions that infants followed the object's directional orientation with their gaze. If the object had a face or if it was faceless, but interacted contingently with another agent, adults described it as 'wanting' something, 'looking' for something, 'trying' to do something, and so on. If, however, it did not have a face and acted only randomly, adults rarely if ever used mentalistic language to describe its behaviour. This result held regardless of whether the object's behaviour was instantiated auditorily (via contingent or random beeping) or visually (via contingent or random wiggling).

7. DIRECTLY EXPERIENCED VERSUS OBSERVED INTERACTION

One important difference characterized the contingent behaviours in the study with adults and the original study with infants. Infants interacted with the object themselves and thus experienced the contingency directly. Adults, however, were not expected to babble spontaneously, nor respond to the object if it acted. Therefore the interactivity of the object was modelled for the adults by a confederate. Using a standard script, the confederate engaged in 'small talk' with the object for 60 s before leaving the subject alone with it. In the contingent conditions, when the confederate spoke to the object, the object beeped or wiggled in response. To ensure that this change did not affect infants' ability to perceive the interactivity of the object, we ran a further infant condition in which they also observed the object interact with a confederate. Like the adults, and the infants before them, they followed the directional orientation of the contingently interacting object, but not the object that beeped randomly.

Some might worry that the data collected under these conditions could reflect attributions by the infant based on cues extrinsic to the object, such as the modelled 'intentional stance' of the confederate. Indeed, a further study with adults showed that some, though not all, of adults' attributions could be accounted for by just such an extrinsic cue. Such an explanation of infants' behaviours would warrant a different theoretical account than the one offered here. Two points argue against this possibility. First, data already discussed suggest that infants of this age are not yet able to exploit that sort of information. In Johnson *et al.* (2001; discussed in § 4) we deliberately tried and failed to elicit mentalistic attributions from 15-month-old infants on the basis of the experimenter's behaviour alone. Without the accompanying mentalistic cues from the object itself, infants failed to make the mentalistic attributions.

Second, although infants certainly have the ability by this age to imitate the intentions of an adult (or an animated, stuffed orangutan), even among more commonplace contexts, infants' imitation abilities are constrained by their ability to make sense of the intention. For example, 11-month-old infants are happy to imitate an adult putting a bird to bed 'to sleep'. They will, however, resist putting a car to bed 'to sleep' even after seeing an adult do so (McDonough & Mandler 1998). The implication is that infants imitate things they can make sense of. It appears that the overt mentalistic attributions of an adult towards another object only makes sense when that other object is already construed as an agent by a child of this age. When and how infants acquire the ability to use only another's stance towards a novel object to categorize it is still an open question.

8. THE ATTRIBUTION OF PERCEPTION/ATTENTION TO MORPHOLOGICALLY AMBIGUOUS OBJECTS: REASONING FROM BEHAVIOURAL CUES ALONE

The work described so far indicates that infants can use either morphological or behavioural information to categ-

Figure 4. The green blob. This object could move around and make noise on its own. (From Johnson *et al.* 2003.)

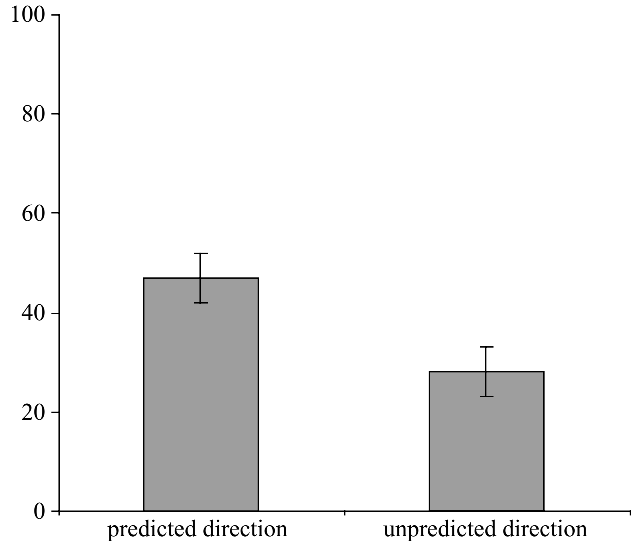

Figure 5. Results from first green blob attentional-following study of Johnson *et al.* (2003). The score on the *y*-axis equals the average percentage of first looks in a given direction across all trials.

orize a novel object as an agent. The evidence for either as an entirely sufficient cue in its own right has not yet been shown. In each case in which infants seemed to have made a mentalistic attribution a combination of cues were present. For instance, in the attentional-following studies of Johnson *et al.* (1998), neither the presence of a face nor the ability to interact contingently was necessary to elicit following from infants—either cue could elicit the behaviour without the other. However, in all cases the object was also animated and had familiar animal-like, if not human, morphology. A face stencilled onto an inert plastic blob might not be a convincing agent, neither might a faceless, plastic blob even if it were animated in appropriately mentalistic ways.

In the following studies we have concentrated on the ability of just one of these cues—behaviour—to elicit mentalistic attributions on its own. Are infants willing to categorize a novel object as an agent even if it bears no perceptual similarity to any familiar agent? To address this issue, we created a new novel object that was intended to be as perceptually unlike any familiar agent as we could make it. The object was the approximate size and shape of an adult's shoe, draped in bright green fibrefill. It could make beeping noises and move on its own around a large black table. It was symmetrical both front to back and side to side and had no distinguishing marks anywhere on its surface. Unlike the original furry brown agent, adults never spontaneously label this 'agent' as anything other than an inanimate object. Anecdotally when shown the object sitting inactive on the table, adults typically describe it as a slipper, lint, cotton candy, etc. (see figure 4).

In our first study with this object (Johnson *et al.* 2003), 14-month-old infants were seated in front of the experimental display and shown the location of two toy target objects at each front corner. Infants then observed an adult confederate engage the object in small talk as before. After the confederate left the room, the infant watched as the object turned to one side or the other. Again, infants' responses were coded as either in the predicted or unpredicted direction. If infants' responses to the original agent were owing to its similarity to familiar animals, looks in this condition, with a very un-animal like object, should be evenly split in the two directions. Figure 5 shows the relative percentages of infants' first looks in each direction. As in the case with the original furry brown agent, infants looked significantly more often in the direction in which the object turned, even though the agent in this case was more perceptually reminiscent of a shoe than an animal.

9. ASSIGNING PERCEPTUAL/ATTENTIONAL ORIENTATION

Although the results described in § 8 were predicted on the assumption of the importance of behaviour in the categorization of agents, they did pose a puzzle of sorts. By stripping the object of any recognizable facial or body features, we also stripped the object of a distinctive front and back. It is one thing to realize that an unfamiliar object is an agent with the ability to perceive the world, it is possibly a separate thing altogether to determine that agent's perceptual orientation. That is, in the absence of eyes and the absence of any relevant asymmetry in the object's shape, how did the infants know which end was the front? Put another way, owing to the object's symmetry and rigidity, a single clockwise rotation of the object could be interpreted by an observer as either the end proximal (or nearest to the observer) turning to the observer's left or as the distal end turning to the observer's right. Regardless of the interpretation, the objective spatio-temporal event witnessed by the observer would be the same. None the less, infants were able to make a systematic judgement about this, without which they would not have produced systematic behaviours.

Given the absence of any detectable facial or head-like features, we proposed that infants would use the apparent ability of the object to *perceive* the confederate and targets to disambiguate its front from its back. That is, they would assume that the side facing the confederate and targets was the front, independent of their own orientation. Of course this prediction holds only on the assumption that infants do categorize the object as an agent—that is, as an object whose behaviour is directed at the world. Importantly, this prediction is agnostic with respect to which specific modality, if any, infants assume the percep-

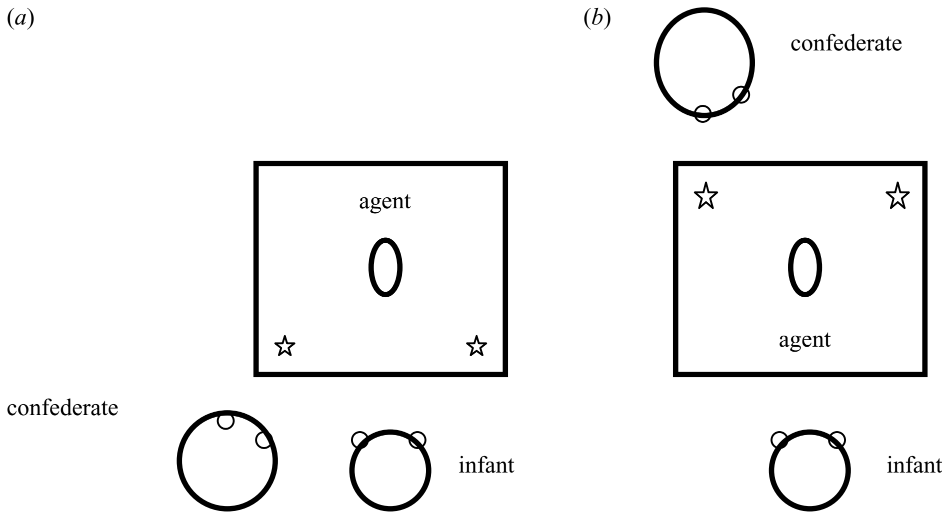

Figure 6. A bird's-eye view of the setup in the orientation assignment study of Johnson *et al.* (2003). (*a*) Proximal condition, (*b*) distal condition.

tion is embedded in (i.e. vision, audition, electromagnetic sensors, etc.).

If this hypothesis is correct, we should be able to control which end infants designate as the object's 'front', and thus which direction they look, by manipulating the location of the confederate and the targets during the interaction. Again, such a result would imply that infants interpreted the behaviour of the object in terms of its *inferred relationship with the world*—a notion at the heart of agency—rather than simply responding to non-relational characteristics of its appearance or movement.

Fourteen-month-old infants participated in one of two conditions (Johnson *et al.* 2003). In both conditions the infants were first shown the targets. They then observed a human confederate engage the agent in the same scripted 'conversation' used before. The two conditions varied only in where the confederate stood during her conversation with the agent and where the targets were placed on the platform. In one condition the confederate stood next to the seated infant, facing the proximal end of the agent. In the other the confederate stood across the table from the infant, facing the distal end of the agent (see figure 6). The targets were placed on the same side as the confederate. After interacting for *ca.* 60 s, the confederate left the room and the agent executed four test trials in which it first beeped loudly then rotated *ca.* 45° in one direction or the other.

In the proximal condition (figure 6*a*) significantly more of infants' first looks away from the object were in the same direction that the proximal end of the object turned than predicted by chance. This replicated the results shown in the previous study. The interesting question is what they did in the distal condition. The observed test event was exactly the same. However, if infants were categorizing the object as an agent with a distinct front through which it perceived the world, the inferred event should have been reversed. That is, infants should now preferentially look in the same direction as the end of the object most distal to themselves.

That is what they did. Infants in the distal condition (figure 6*b*) reversed their looking behaviour relative to infants in the proximal condition. Significantly more of the first looks away from the object were in the direction of the distal end, rather than the canonical proximal end. In effect, infants behaved as though they were watching an agent from behind. These results are remarkable not only because infants in this context did not need facial features to cue their looking, but they were also able to override any potential prepotent egocentric tendencies to treat the side facing them as the front. How exactly infants accomplished this and how they represented the hidden 'face' to themselves, remains to be seen.

Based on these results we can tentatively conclude that around the end of the first year, infants are able to categorize a completely novel object as a mentalistic agent on the basis of its behaviour alone. In the studies described so far they seem to be reasoning not only about the ability of the object to perceive or attend to the world, but the actual geometric orientation of the object that would make that most plausible.

10. THE ATTRIBUTION OF GOALS TO MORPHOLOGICALLY AMBIGUOUS OBJECTS: REASONING FROM BEHAVIOURAL CUES ALONE

Returning again to our original empirical strategy, we hoped to test whether infants would attribute other putative mental states to the novel green blob using different behavioural measures from those involved in attentional following. As before, we chose the attribution of goals as an important test. Previously we showed that infants would attribute goals to an agent that looked in many ways like a human. The current study was designed to test whether they would also attribute goals to an agent that was entirely unlike any agent the infant was likely to have seen.

Importantly, the orangutan agent in the previous goal study (Johnson *et al.* 2001) had articulated hands. This had two advantages not available in the current study. First, the hands allowed the agent to manipulate objects in a variety of ways. This provided a wide range of possible object-directed goals for testing purposes. In contrast, the current agent has no articulated parts of any sort. This restricted the possible object manipulations to varieties of pushing actions, thereby limiting the overall attractiveness of the method.

Second, with the possession of an articulated set of hands, the mapping between actions the infant observed and actions the infant needed to produce was (relatively) straightforward. In contrast, an infant observing the green blob act on objects would gain little information about how to produce the same outcomes with their own, very different, body. This lack of correspondence has important task demand implications for us. To the extent that infants observe goals that are achieved through means—actions that cannot be easily mapped onto their own action patterns, a failure to imitate is difficult to interpret.

To avoid these issues we sought a methodology that would be both sensitive to goal attributions and also appropriate for use with infants of this age given this agent. The work by Woodward (1998) provides such a method. This used the visual habituation method to test whether infants encode human actions as the goals of the actor, or solely as the spatio-temporal movements involved. One group of infants were habituated to a hand approaching one of two toys on a stage. In the test events, one of two things changed, either (i) the spatio-temporal path of the hand, or (ii) its target object. Woodward reasoned that if infants encoded the hand's action as *goal*-directed (reflecting an agent–world relationship), test trials in which the goal changed should be more novel, and therefore more interesting, than those in which the path changed. Indeed, infants less than a year old dishabituated to the change in the hand's target relative to the change in the hand's path. A separate group of infants habituated and tested on identical events in which the 'agent' was a rod instead of a hand, exhibited quite different patterns. These infants did not dishabituate to the change in the target object of the rod, indicating that they had not encoded the *relationship* between the rod and the object as an important aspect of the event.

The results of Woodward (1998) indicate that even before the end of the first year, infants recognize that:

(i) the behaviour of some (but not all) entities is directed at the world; and
(ii) the identity of the entity's target is relevant, i.e. the content of the relationship is represented.

We can therefore say that infants attribute an intentional relationship between the object and the world (i.e. one based on content).

Like Meltzoff (1995); Woodward (1998) argued that infants' reasoning about goals and mental states is restricted to their reasoning about humans. However, like Meltzoff (1995), Woodward (1998) showed that infants exclude some objects from their agent category, not that they include only humans. Like the non-agentive pincers of Meltzoff (1995), the rod of Woodward (1998), though grossly similar to a human arm and hand, shows none of the specific putative behaviour or morphology of agents. To adequately demonstrate a person-only reasoning domain, infants need to be tested with more theoretically motivated non-human 'agents'.

Shimizu & Johnson (2003) tested these claims by showing 12-month-old infants the novel green blob in a procedure based on the dishabituation method of Woodward (1998) that compared changes in spatio-temporal path to changes in target object. To make the behavioural test as strong as possible, two groups of infants were tested with the same green blob. The only difference between the two groups was the behaviour of the novel object in the introduction and habituation phases of the study. In an agent condition, infants were introduced to the object with our now-standard confederate conversation. The confederate talked to the object and the object beeped back. In the non-agent condition the confederate remained silent while the object beeped its way through the same script (thus appearing random). In addition, at the beginning of each habituation trial, the agentive blob began its action facing the 'non-goal' object, thus requiring a deliberate 'choice' to turn toward the 'goal' before beginning its approach. In comparison the non-agentive blob simply began each habituation trial facing in the same direction that it ultimately moved—towards the target object.

Infants in both conditions saw exactly the same test events—one in which the green blob's trajectory was changed, but its target object was not, and one in which the blob's target object was changed, but the trajectory itself remained unchanged. Unlike in the habituation trials, in the test trials, the green blob always began its action oriented in the direction it moved, regardless of condition.

None the less, these two conditions, the interactive, choice-making agent versus the non-interactive mechanical-like non-agent, yielded quite different interpretations from the infants. Infants in the non-agent condition treated the two test outcomes (changes in trajectory versus changes in target) equivalently. Nothing in their behaviour indicated that they selectively attended to the relationship between the blob and the objects in its immediate world. Infants in the agent condition acted quite differently however. They looked significantly longer at the test events in which the target of the blob's action changed compared with those events in which the trajectory of the blob's action changed. As in the studies of Woodward (1998), this indicates that infants coded the relationship between the blob's actions and a specific object in the world to the exclusion of other more superficial or perceptual aspects of the events that they could have attended to. Thus, we can conclude that infants considered the interactive, choice-making blob to be an agent, just like a human. The fact that infants in the other condition did not reach that conclusion when they observed the very same object behave in non-agentive ways strengthens the case that it is the behaviour, not the appearance of the object, that infants used in making their interpretations.

11. THE RELATIONSHIP BETWEEN AGENCY AND METAREPRESENTATIONS: THE CASE OF AUTISM

It is tempting to predict that people with autism, now famous for their inability to read minds (Baron-Cohen *et al.* 1985, 1993; Baron-Cohen 1995), would be incapable of detecting or following the attentional orientation of the novel objects described in this paper. It is, after all, well documented that people with autism do not spontaneously follow the gaze of other humans (e.g. Leekam *et al.* 1997). Preliminary results from our laboratory, however, indicate that this prediction is premature (Giovanelli & Johnson 2003). A group of older autistic children and adolescents were introduced to the faceless furry brown agent in the same manner used with typical adults and infants—a confederate engaged the agent in a brief conversation and then left the room. When the agent then turned away from participants, the participants turned reliably and spontaneously to look in the direction of its turn. In a non-interactive control condition, participants did not follow the turns.

These results lead to immediate further questions about the development of theory of mind both in general and in autism specifically. In general, additional experiences and/or cognitive mechanisms than those discussed here must clearly be involved in typical development. The additional pieces of the developmental puzzle could come in the form of other specialized mechanisms (see, for instance, the multi-mechanism accounts of theory of mind by both Baron-Cohen (1995) and Leslie (1994, 1995)). Alternatively, further development could depend on more general theory-building abilities (see, for instance, Gopnik & Wellman (1994) and Perner (1991)).

In addition, although it is now well documented that people with autism have difficulty reasoning about other people's higher-order mental states such as beliefs, is this difficulty uniform across the agent domain? Do people with autism also fail to attribute false beliefs to non-humans, e.g. dogs? Although there is scant existing evidence about autistics' conceptions of animals, at least one recent study suggests that their social aversion is restricted to people. In direct contrast to an atypical preference for inanimates over people, tests of their preferences for animals did not differ from typically developing children (Celani 2002). Is the core difficulty therefore with *metarepresentation* in all its manifestations, or with *people* in all their manifestations? These new findings might provide an additional wedge with which to approach the question.

Regardless of how this question is ultimately answered, the results from autism demonstrate that the ability to divide the world into agents and non-agents may be necessary, but is clearly not sufficient for the normal development of theory of mind.

12. CONCLUSIONS

The studies described here challenge assumptions about the scope and origins of humans' mentalistic reasoning. Twelve- to fifteen-month-old infants were shown to treat novel self-moving objects as though they have both perception/attention, communicative abilities and goals if they either look like an agent (i.e. have a face) or behave in specific ways (e.g. are contingently interactive with other known agents). The infants were able to detect the highly abstract temporal relationship between actors whether they themselves were one of the actors or not. Surprisingly, no evidence has yet been found within these studies to indicate that self-movement alone will elicit this interpretation from infants of this age. Neither did infants of this age appear willing or able to infer an object's agenthood solely on the basis of how an adult treated it. Impressively, it seems that once infants did categorize an object as an agent they actively used the geometric information implicit in its interactions with its environment to infer its perceptual/attentional orientation.

The scope of the agent category implied by these findings is far broader than the category of people. Neither do the findings seem to be easily accounted for by a non-mentalistically interpreted similarity metric with people. Similarity metrics require dimensions. Morphological features, interactivity and self-movement are all possible highly salient dimensions of humans that infants might use to generalize. None the less, infants of this age seem to ignore some morphological features (animal shape, colour and texture) and self-movement as relevant dimensions in their own right for these inferences.

Despite adults' obvious *understanding and beliefs* that the novel objects shown to infants were artefacts and thus not true agents, the objects elicited very similar interpretations in adults to those elicited in infants. This finding suggests that the representational system underlying the infants' attributions is not open to revision. If it were adults would have long since revised it out of existence. By implication then, the system is not a constructed one.

Preliminary evidence tentatively shows that the system typically used to recognize agents is also available in autism. This is consistent with the view that the input system for the social reasoning system is dissociable from other parts of the system, such as the part responsible for handling metarepresentations.

Taken together, the evidence from infants' reasoning about truly ambiguous unfamiliar objects (e.g. novel green blobs) suggests that at least by the age of 1 year, humans have a very abstract representational system for detecting and reasoning about social agents. Whether it is the same system that represents the configural and movement patterns of humans such as described elsewhere in this volume is an open question. Perhaps the human body-centric input system for the social reasoning circuit described by Frith & Frith 2003; (STS) is only one of multiple input systems. Alternatively, perhaps STS includes representational abilities that have not yet been described, including the ability to represent temporal relationships between entities independent of their appearance.

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REFERENCES

Baldwin, D. A. & Moses, L. J. 1996 The ontogeny of social information gathering. *Child Dev.* **67**, 1915–1939.

Baron-Cohen, S. 1995 *Mindblindness: an essay on autism and theory of mind*. Cambridge, MA: MIT Press.

Baron-Cohen, S., Leslie, A. M. & Frith, U. 1985 Does the autistic child have a 'Theory of Mind'? *Cognition* **21**, 37–46.

Baron-Cohen, S. Tager-Flusberg, H. & Cohen, D. (eds) 1993 *Understanding other minds: perspectives from autism*. Oxford University Press.

Bassili, J. N. 1976 Temporal and spatial contingencies in the perception of social events. *J. Personality Soc. Psychol.* **33**, 680–685.

Bates, E., Camaioni, L. & Volterra, V. 1975 The acquisition of performatives prior to speech. *Merrill-Palmer Q.* **21**, 205–226.

Bretherton, I., McNew, S. & Beeghly-Smith, M. 1981 Early person knowledge as expressed in gestural and verbal com-

munications: when do infants acquire a 'theory of mind'? In *Infant social cognition* (ed. M. E. Lamb & L. R. Sherrod), pp. 333–374. Hillsdale, NJ: Lawrence Erlbaum Associates.
Butterworth, G. E. & Grover, L. 1988 The origins of referential communication in human infancy. In *Thought without language* (ed. L. Weiskrantz), pp. 5–24. Oxford University Press.
Butterworth, G. & Jarrett, N. 1991 What minds have in common is space: spatial mechanisms serving joint visual attention in infancy. *Br. J. Devl Psychol.* **9**, 55–72.
Carey, S. & Spelke, E. 1994 Domain-specific knowledge and conceptual change. In *Mapping the mind: domain specificity in cognition and culture* (ed. L. A. Hirschfeld & S. A. Gelman), pp. 169–200. New York: Cambridge University Press.
Carey, S. & Spelke, E. 1996 Science and core knowledge. *Phil. Sci.* **63**, 515–533.
Celani, G. 2002 Human beings, animals and inanimate objects: what do people with autism like? *Autism* **6**, 93–102.
Corkum, V. & Moore, C. 1998 The origins of joint visual attention in infants. *Devl Psychol.* **34**, 28–38.
Dennett, D. 1978 Response to Premack, D. & Woodruff, G. Does the chimpanzee have a theory of mind? *Behav. Brain Sci.* **4**, 568–570.
D'Entremont, B., Hains, S. M. J. & Muir, D. W. 1997 A demonstration of gaze following in 3- to 6-month-olds. *Infant Behav. Dev.* **20**, 569–572.
Ellsworth, C., Muir, D. & Hains, S. 1993 Social competence and person–object differentiation: an analysis of the still-face effect. *Devl Psychol.* **29**, 63–73.
Field, T. M., Woodson, R., Greenberg, R. & Cohen, D. 1982 Discrimination and imitation of facial expressions by neonates. *Science* **218**, 179–181.
Fodor, J. A. 1983 *The modularity of mind: an essay on faculty psychology*. Cambridge, MA: MIT Press.
Frith, U. & Frith, C. D. 2003 Development and neurophysiology of mentalizing. *Phil. Trans. R. Soc. Lond.* B **358**. (In this issue.) (DOI 10.1098/rstb.2002.1218.)
Frye, D., Rawling, P., Moore, C. & Myers, I. 1983 Object–person discrimination and communication at 3 and 10 months. *Devl Psychol.* **19**, 303–309.
Gerwitz, J. L. & Pelaez-Nogueras, M. 1992 Social referencing as a learned process. In *Social referencing and the social construction of reality in infancy* (ed. S. Feinman), pp. 151–173. New York: Plenum.
Gibson, E. J., Owsley, C. J. & Johnson, J. 1978 Perception of invariants by 5-month-old infants: differentiation of two types of motion. *Devl Psychol.* **14**, 407–416.
Giovanelli, J. & Johnson, S. C. 2003 The attribution of minds to novel objects by autistic children and adolescents (In preparation.)
Gopnik, A. & Meltzoff, A. 1997 *Words, thoughts, and theories*. Cambridge, MA: MIT Press.
Gopnik, A. & Wellman, H. M. 1994 The theory theory. In *Mapping the mind: domain specificity in cognition and culture* (ed. L. A. Hirschfeld & S. A. Gelman), pp. 257–293. New York: Cambridge University Press.
Heider, F. & Simmel, M. 1944 An experimental study of apparent behavior. *Am. J. Psychol.* **57**, 243–259.
Hood, B. M., Willen, J. D. & Driver, J. 1998 Adults' eyes trigger shifts of visual attention in human infants. *Psychol. Sci.* **9**(2), 131–134.
Johnson, S. C. 2000 The recognition of mentalistic agents in infancy. *Trends Cogn. Sci.* **4**, 22–28.
Johnson, S. C., Slaughter, V. & Carey, S. 1998 Whose gaze will infants follow? Features that elicit gaze-following in 12-month-olds. *Devl Sci.* **1**, 233–238.
Johnson, S. C., Booth, A. & O'Hearn, K. 2001 Inferring the goals of non-human agents. *Cogn. Dev.* **16**, 637–656.
Johnson, S. C., Bolz, M., Carter, E., Mandsangar, J., Teichner, A. & Zettler, P. 2003 Inferring the attentional orientation of morphologically novel agents in infancy. (In preparation.)
Leekam, S., Baron-Cohen, S., Perret, D., Milders, M. & Brown, S. 1997 Eye-direction detection: a dissociation between geometric and joint attention skills in autism. *Br. J. Devl Psychol.* **15**, 77–95.
Legerstee, M. 1991 The role of person and object in eliciting early imitation. *J. Exp. Child Psychol.* **51**, 423–433.
Legerstee, M. 1992 A review of the animate-inanimate distinction in infancy: implications for models of social and cognitive knowing. *Early Dev. Parenting* **1**, 59–67.
Legerstee, M. 1994 Patterns of 4-month-old infant responses to hidden silent and sounding people and objects. *Early Dev. Parenting* **3**, 71–80.
Legerstee, M. 1997 Contingency effects of people and objects on subsequent cognitive functioning in 3-month-old infants. *Social Dev.* **6**, 307–321.
Legerstee, M., Pomerleau, A., Malcuit, G. & Feider, H. 1987 The development of infants' responses to people and a doll: implications for research in communication. *Infant Behav. Dev.* **10**, 81–95.
Lempers, J. D. 1979 Young children's production and comprehension of nonverbal deictic behaviors. *J. Genet. Psychol.* **135**, 93–102.
Leslie, A. M. 1994 ToMM, ToBy, and agency: core architecture and domain specificity. In *Mapping the mind: domain specificity in cognition and culture* (ed. L. A. Hirschfeld & S. A. Gelman), pp. 119–148. New York: Cambridge University Press.
Leslie, A. M. 1995 A theory of Agency. In *Causal cognition: a multidisciplinary debate* (ed. D. Sperber, D. Premack & A. J. Premack), pp. 121–141. Oxford: Clarendon Press.
Leung, E. H. L. & Rheingold, H. L. 1981 Development of pointing as a social gesture. *Dev. Psychol.* **17**, 215–220.
Lycan, W. 1999 Intentionality. In *MIT Encyclopedia of Cognitive Science* (ed. R. Wilson & F. Keil), pp. 413–415. Cambridge, MA: MIT Press.
McDonough, L. & Mandler, J. M. 1998 Inductive generalization in 9- and 11-month-olds. *Devl Sci.* **1**, 227–232.
Meltzoff, A. N. 1995 Understanding the intention of others: re-enactment of intended acts by 18-month-old children. *Devl Psychol.* **31**, 838–850.
Meltzoff, A. N. & Moore, M. 1983 Newborn infants imitate adult facial gestures. *Child Dev.* **54**, 702–709.
Meltzoff, A. N. & Moore, M. K. 1977 Imitation of facial and manual gestures by human neonates. *Science* **198**, 75–78.
Moore, C. & Corkum, V. 1994 Social understanding at the end of the first year of life. *Devl Rev.* **14**, 349–372.
Morton, J. & Johnson, M. M. 1991 CONSPEC and CONLERN: a two-process theory of infant face recognition. *Psychol. Rev.* **98**, 164–181.
Moses, L. J., Baldwin, D. A., Rosicky, J. G. & Tidball, G. 2001 Evidence for referential understanding in the emotions domain at twelve and eighteen months. *Child Dev.* **72**, 718–735.
Perner, J. 1991 *Understanding the representational mind*. Cambridge, MA: MIT Press.
Poulin-Dubois, D. 1999 Infants' distinction between animate and inanimate objects: the origins of naive psychology. In *Early social cognition* (ed. P. Rochat), pp. 257–280. Hillsdale, NJ: Lawrence Erlbaum Associates.
Poulin-Dubois, D., Lepage, A. & Ferland, D. 1996 Infants' concept of animacy. *Cogn. Dev.* **11**, 19–36.
Premack, D. 1990 The infant's theory of self-propelled objects. *Cognition* **36**, 1–16.
Premack, D. 1991 The infant's theory of self-propelled objects. In *Children's theories of mind: mental states and social under-*

standing (ed. D. Frye & C. Moore), pp. 39–48. Hillsdale, NJ: Lawrence Erlbaum Associates.
Repacholi, B. M. & Gopnik, A. 1997 Early reasoning of desires: evidence from 14- to 18-month-olds. *Devl Psychol.* **33**, 12–21.
Ricard, M. & Allard, L. 1993 The reaction of 9- to 10-month-old infants to an unfamiliar animal. *J. Genet. Psychol.* **154**, 5–16.
Rock, I. 1983 *The logic of perception*. Cambridge, MA: MIT Press.
Rovee-Collier, C. K., Earley, L. & Stafford, S. 1989 Ontogeny of early event memory: III. Attentional determinants of retrieval at 2 and 3 months. *Infant Behav. Dev.* **12**, 147–161.
Scaife, J. F. & Bruner, J. S. 1975 The capacity for joint visual attention in the infant. *Nature* **253**, 265–266.
Scholl, B. J. & Tremoulet, P. D. 2000 Perceptual causality and animacy. *Trends Cogn. Sci.* **4**, 299–309.
Shimizu, Y. A. & Johnson, S. C. 2003 The attribution of goals to morphologically novel agents by twelve-month-olds. (In preparation.)
Slater, A. & Quinn, P. C. 2001 Face recognition in the newborn infant. *Infant Child Dev.* (Special Issue: Face Processing in Infancy and Early Childhood) **10**, 21–24.
Slater, A., Bremner, G., Johnson, S. P., Sherwood, P., Hayes, R. & Brown, E. 2000 Newborn infants' preference for attractive faces: the role of internal and external facial features. *Infancy* **1**, 265–274.
Spelke, E., Phillips, A. & Woodward, A. 1995 Infants' knowledge of object motion and human action. In *Causal cognition: a multidisciplinary debate* (ed. D. Sperber, D. Premack & A. Premack), pp. 44–78. Oxford: Clarendon Press.
Watson, J. S. 1972 Smiling, cooing, and 'the game'. *Merrill-Palmer Q.* **118**, 323–340.
Watson, J. S. 1979 Perception of contingency as a determinant of social responsiveness. In *Origins of the infant's social responsiveness: the Johnson & Johnson baby products company pediatric round table*, II (ed. E. G. Thoman), pp. 33–64. Hillsdale, NJ: Lawrence Erlbaum.
Wellman, H. M. 1993 Early understanding of mind: the normal case. In *Understanding other minds: perspectives from autism* (ed. S. Baron-Cohen, H. Tager-Flusberg & D. J. Cohen), pp. 10–39. Oxford University Press.
Woodward, A. 1998 Infants selectively encode the goal object of an actor's reach. *Cognition* **69**, 1–34.

GLOSSARY

STS: superior temporal sulcus