Infants' understanding of the epistemic nature of eye gaze during the second year of life

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ABSTRACT

Infants' understanding of the epistemic nature of eye gaze during the second year of life

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The current thesis explored infants' implicit understanding of mental states during the second year of life. The first paper focused on infants' appreciation of the relationship between visual perception and knowledge. Based on an interactive search task, 24-month-olds demonstrated an understanding that people's eyes need to be unobstructed in order for them to be connected to the external world. Using a preferential looking paradigm, 18-month-olds predicted different behavior as a function of a person's visual experience. The second paper employed the preferential looking paradigm to investigate 18-month-olds' attributions of knowledge or ignorance when looking behavior was displayed by a person or a humanoid robot. Infants predicted different behavior as a function of the person's visual experience, while they did not demonstrate this expectation in the robot condition. The third paper explored infants' understanding of the epistemic nature of eye gaze within the context of a word learning task (Baldwin, 1993). In three experiments 18-month-olds were exposed to either a human or robot speaker who uttered novel labels for unfamiliar objects under two different eye gaze conditions. While infants followed the eye gaze of the non-human speaker, they did not use the robot speaker's eye gaze cues to determine the correct referent of novel words, even when contingent interaction was added. When the speaker was human, infants used the speaker's eye gaze to determine the correct referent.

Together, the findings from the studies presented in this dissertation suggest that by 18 months, infants possess an implicit appreciation of the relationship between visual perception and knowledge. The results also provide evidence for the notion that by 18 months, the scope of infants' concept of mentalistic agent has narrowed relative to that demonstrated by younger infants.

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Chapter 1. General Introduction

Eye gaze plays a unique and important role in human interactions. In many situations, eye gaze affords us with information about another person's focus of attention. Eye gaze cues can also serve an even deeper function as they reveal information about another person's state of mind, such as intentions, knowledge, desires, and beliefs. That is, eye gaze cues provide us with information about a person's mental state that enables us to predict how an individual may behave in a given situation and may also affect our own behavior. We also tend to rely on other's eye gaze cues to interpret the expression of emotions, such as desire or intimacy (Langton, Watt, & Bruce, 2000). Indeed, the ability to use eye gaze to reveal another person's mental activities or for "mind reading" appears to be unique to humans (Baron-Cohen, 1995). Given the critical role that eye gaze serves in adults' interactions, perceptions, and interpretations of other's behavior, researchers have speculated that the ability to use eye gaze is crucial to the development of a theory of mind (Gopnik, Slaughter, & Meltzoff, 1994). Furthermore, lack of sensitivity to eye gaze is related to impairments in social and cognitive abilities such as those associated with autism spectrum disorders (Baron-Cohen, 1995).

While there is little debate that adults understand the epistemic nature of eye gaze and appreciate that looking behavior results in a unique visual experience for the looker, there is less consensus about the extent to which children understand the mentalistic nature of eye gaze and when this ability comes to approximate that of adults. Specifically, in the past decade, developmental researchers have focused on elucidating the meaning of infants' gaze following behavior and examining the extent to which young infants will make mentalistic attributions on the basis of eye gaze. As with other developmental abilities, infants' understanding of eye gaze and the extent to which infants understand the epistemic nature of eye gaze appears to develop gradually.

In a seminal paper addressing the developmental origins of visual perception, Povinelli and Eddy (1996) proposed that there are several different levels of eye gaze understanding. At the most basic level, the organism possesses a special sensitivity to eyes which is present shortly after birth (Flom, Lee, & Muir, 2007). At the second level, the organism notices direction of eye gaze and may respond accordingly, but does not appreciate anything about the function of the eyes or their significance in terms of what they may reflect about mental significance. This level of understanding of eye gaze is evident throughout the animal kingdom, and is not necessarily unique to humans. For instance, it is well documented that a variety of species, including reptiles, birds, and mammals show sensitivity to and exhibit different behaviors on the basis of another's direction of eye gaze (see Povinelli & Eddy, 1996). While this level of eye gaze understanding is useful in that it serves to orient an organism toward important events in the environment, it does not require an understanding of others' minds. With respect to humans, infants show a preference for eyes over other parts of the human face shortly after birth (Caron, Caron, Roberts, & Brooks, 1997) and by 3 to 6 months of age, begin to follow an adult's direction of eye gaze to objects within their visual field (D'Entremont, Hains, & Muir, 1997). However, this behavior does not necessarily reflect an understanding of the mental experience of seeing. Thus, many animal species and very young human infants are capable of understanding eye gaze at this most basic level: they are sensitive to eyes from shortly after birth and orient based on the direction of eye gaze, but there is no evidence that they understand any of the mentalistic properties or consequences of visual perception.

At the third level, organisms can appreciate that vision subjectively links individuals to the external world and are aware that eye gaze can reflect attentional focus (Povinelli & Eddy, 1996). In this way, at the third level of eye gaze understanding there is a rudimentary understanding of the epistemic nature of gaze. As such, eye gaze is understood as an intentional behavior that is directed purposefully toward objects or events in the world. Evidence suggests that human infants appreciate the subjective, referential nature of eye gaze and understand that eyes provide the looker with visual access to the external world by early in the second year of life. Specifically, by 10 to 11 months of age, infants appear to understand that eyes are critical for looking. They are sensitive to the status of an adult's eyes, and follow gaze when an adult's eyes are open, but do not do so when an adult's eyes are closed (Brooks & Meltzoff, 2002; Meltzoff & Brooks, 2007). At the end of the first year, infants also begin to demonstrate an appreciation that looking involves an attentional focus. For example, by 8 months infants expect a person's gaze to be directed at a specific referent object (Csibra & Volein, in press), and by 12 months infants notice when a looker changes the focus of her attention from one object to another (Woodward, 2003). From 9 to 14 months, infants also begin to demonstrate joint attention behaviors (Butterworth & Jarrett, 1991); they are aware that both self and other are attending to the same object or event and will frequently alternate their gaze between the object of shared visual attention and the other person. Furthermore, 12-month-olds will crawl or walk a short distance in order to look at what an adult is looking at behind a barrier (Moll & Tomasello, 2004), and 14-month-olds will follow an adult's gaze behind a barrier when the adult is deemed a 'reliable' looker, but not when they believe that the looker is 'unreliable' (Chow, Poulin-Dubois, & Lewis, in press). Slightly older infants (16- to 18-month-olds) show a more sophisticated understanding of the attentional focus of vision, and use eye gaze along with other directional cues, to determine the correct referent of novel words (Baldwin, 1993, 1995). Thus, several lines of research that suggest infants demonstrate the third level of gaze understanding by the end of the first year or life. They appreciate the referential nature of eye gaze and understand that vision subjectively links individuals to the world around them.

At the fourth level of gaze understanding, organisms appreciate the mental consequences of seeing (Povinelli & Eddy, 1996). Thus, at this most complex level, there is an awareness of the relationship between visual perception and unobservable mental states such as knowledge, thoughts, desires, and other emotions. This appreciation is more sophisticated than merely understanding that visual perception provides a looker with a connection to the external world, and emphasizes the recognition that people can perceive an event differently and consequently may hold different beliefs or knowledge about the event as a result of their visual perception. In this vein, it has been proposed that development of eye gaze understanding and development of theory of mind are linked, as an understanding of visual perception may aid in developing a better understanding of mental states (Gopnik et al., 1994). To date, the preponderance of evidence suggests that children do not explicitly understand the relationship between visual perception and mental states until the preschool age. Specifically, it is not until 4 years of age that children demonstrate that they understand the causal role that visual perception plays in the acquisition of knowledge. For instance, 4-year-olds understand that someone who looked inside a container will know what it contains, while someone who did not look inside will be ignorant (Pillow, 1989; Povinelli & de Blois, 1992; Pratt & Bryant, 1990; Wimmer, Hogrefe, & Perner, 1988; Woolley & Wellman, 1993). While 4-year-olds appear to understand that visual perception plays a critical role in knowledge formation, 3-year-olds seem to appreciate that vision and knowledge go together, but they do not understand that vision is necessary for knowledge (Perner, 1991). To date, even studies using simplified procedures have failed to demonstrate that children explicitly understand the relationship between visual perception and knowledge prior to the age of three (Povinelli & de Blois, 1992).

However, absence of an *explicit* understanding of the relationship between visual perception and knowledge prior to age four does not necessarily mean that younger children are wholly incapable of understanding anything like it. In fact, as an understanding of most concepts develops gradually, it is reasonable to assume that children may possess an *implicit*, less sophisticated understanding of the relationship between visual perception and knowledge prior to the age of four years. Indeed, similar patterns of development have been documented in regard to other epistemic states. For example, children's looking responses demonstrate that they understand a story character's belief prior to the age that they are able to demonstrate their understanding through verbal responses to questions (Clements & Perner, 1994). Several studies lend credence to the notion that a similar pattern may exist for children's understanding of the relationship between visual perception and knowledge. For example, 2-year-olds have been found to make more frequent and explicit attempts to communicate with their mother when she was ignorant to the location of an object than when she was not (O'Neill, 1996), and adjust their behavior on the basis of the parent's visual access (Dunham, Dunham, & O'Keefe, 2000). Thus, these findings suggest that children likely possess an implicit, rudimentary understanding of the relationship between visual perception and knowledge before their third birthday. As such, there appears to be evidence for subtle changes in infants' understanding of the relationship between visual perception and knowledge, which follow or coincide with level two understanding of eye gaze and may serve as a precursor to the sophisticated level of understanding of eye gaze that is exhibited by preschoolers and adults (i.e., level four understanding).

Because mental states are unobservable, they are often inferred rather than perceived directly, and it is often difficult to come to a firm conclusion about whether infants appreciate the mentalistic nature of eye gaze. As a result, there is controversy about the extent to which infants' gaze following behavior reflects an understanding of the epistemic nature of eye gaze. To further address this issue, researchers have also focused on examining infants' developing concept of mentalistic agent. Whether infants appreciate that mental states are uniquely human, and if so, when this understanding develops, has been of critical interest. Furthermore, if infants attribute mental states differently to human and non-human agents, delineating the features or characteristics that infants rely on to distinguish mentalistic agents from those that are incapable of such feats, is of key importance.

To date, the majority of research examining the origin of infants' concept of mentalistic agents has focused on the attribution of goal-directed behavior in young infants before their first birthday (e.g., Biro & Leslie, 2007; Csibra & Gergely, 1998;

Johnson, Shimizu, & Ok, 2007; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Kuhlmeier, Wynn, & Bloom, 2003; Luo & Baillargeon, 2005; Shimizu & Johnson, 2004). The results of these studies typically demonstrate that infants in the first year of life attribute goal-directed behavior to inanimate agents quite readily. For example, Luo and Baillergeon (2005) demonstrated that 5-month-olds interpret the action of a self-propelled box as goal directed. Few studies have directly examined infants' concept of mentalistic agent within the context of gaze following behavior. The first researchers to address this issue, Johnson, Slaughter, and Carey (1998), examined the conditions under which infants would follow the gaze of a non-human agent. They demonstrated that 12- to 15-month-olds followed the gaze of a novel object (a fuzzy, amorphous blob) when it possessed facial-like features, or when it had interacted in a contingent manner with the infant, or when it displayed both of these characteristics. Moreover, infants were no more likely to follow the gaze of an unfamiliar person than the contingently interacting novel object with facial features.

Consequently, on the basis of these results and similar findings regarding infants' attribution of goal-directed behavior to inanimate agents, some researchers have concluded that in the first year of life, infants' concept of mentalistic agent is broad and abstract. Thus, it has been proposed that infants attribute mental states broadly, based on mechanisms designed to detect any goal-directed action, regardless of the identity of the actor. In particular, it has been proposed that infants' attributions of intentional behavior are activated whenever they recognize an object as a psychological agent, based on an evolutionary designed system which is sensitive to certain behavioral cues (Baron-Cohen, 1995; Csibra, Gergely, Bíró, Koós, & Brockbank, 1999; Gergely, Nádasdy, Csibra, &

Bíró, 1995; Johnson, 2000; Leslie, 1995). Conditions that are believed to successfully elicit goal-attributions include equifinality of actions (Gergely et al., 1995; Kamewari et al., 2005), action effects (Biro & Leslie, 2007; Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003), appearance of rationality (Gergely et al., 1995), self-propelled motion (Baron-Cohen, 1995; Luo & Baillargeon, 2005), temporal and spatial contingency (i.e., contingent interaction) (Johnson, 2000; Johnson et al., 1998; Shimizu & Johnson, 2004), and internally driven changes in trajectory (Shimizu & Johnson, 2004; Tremoulet & Feldman, 2000). Thus, according to this cue-based view, infants attribute goal-directedness to an action independent of the perceptual appearance of the agent and do so on the basis of these behavioral cues. Overall, the cue-based view proposes that infants attribute goal directed behavior to a wide range of entities, including unfamiliar inanimate agents, and do not interpret human and non-human actions differently.

While the evidence cited above suggests that infants attribute goal directed behavior to non-human agents and follow the gaze of non-human agents, there is also evidence that suggests young infants do indeed treat people and inanimate objects differently. For example, research examining infants' concept of agent at a later age and on more sophisticated mind-reading skills, such as attributions of intent, suggests that infants restrict mentalistic attributions only to humans. For example, Meltzoff (1995) examined 18-month-olds' responses when they witnessed a person or a self-propelled mechanical device perform a failed/incomplete action. The infants in this study inferred the person's goal and completed the target action, even though they had never seen the action completed in its entirety, only when they observed the action completed by the person. The same infants failed to do so after they observed the mechanical device perform the same incomplete action (but see also Johnson, Booth, & O'Hearn, 2001). Based on these results, others have argued that by 18 months of age, infants understand that people are uniquely capable of intentional actions and appreciate that inanimate objects are not capable of such intent. Further research suggests that even younger infants attribute goals differently to human and inanimate entities. For example, using a visual habituation procedure, Woodward (1998) demonstrated that 6- and 9-month-olds interpreted the action of a human hand as goal directed while they did not interpret the same action as goal-directed when the agent was inanimate (i.e., rod, mechanical claw, or flat occluder shaped like a human arm and hand). These findings contrast with the cue-based view and suggest that by 6 months, infants interpret the actions of humans as goal directed, while they do not do so when an inanimate object performs the same action. Based on these findings, researchers have proposed that infants restrict attributions of intent to human action and do not attribute mental states broadly. Moreover, it is proposed that infants acquire this understanding gradually through experiences with human agents (i.e., from their own actions and interactions with social partners) (Meltzoff, 1995; Tomasello, 1999; Woodward, Sommerville, & Guajardo, 2001).

The current thesis was designed to examine infants' understanding of eye gaze in the second year of life, a critical period in infants' emerging understanding of mental states. The first paper is focused on examining infants' appreciation of the causal relationship between visual perception and knowledge. It is well-documented that it is not until age three that children fully appreciate that visual perception is necessary for knowledge acquisition (Povinelli & de Blois, 1992). However, infants possess many of the building blocks necessary to understand this relationship by the end of the first year of life. What remains unclear is whether infants have some grasp that eye gaze can be used to make inferences about another person's knowledge. This issue was examined more closely in the first paper. In the first experiment, two interactive search tasks were used to investigate 24- and 30-month-old infants' understanding of the relationship between eye gaze and knowledge. The first task was designed to examine whether infants appreciate that a person's eyes must be unobstructed in order for that person to be visually connected to the external world. Specifically, we questioned whether infants would differentially enlist the help of a person who could see or a person who was blindfolded to retrieve a hidden toy. The second task was also designed to ascertain whether infants understand that seeing affords a person with knowledge, although the child did not have to infer the adults' knowledge to obtain the object. The issue of interest here was whether infants would infer that a person would know the correct location of a hidden toy, based on whether or not the person could see when critical information was presented. In the second and third experiments, a preferential looking procedure was designed to further examine whether infants have a rudimentary understanding of the relationship between visual perception and knowledge. Specifically, these experiments employed a violation of expectancy paradigm to examine 18- and 24-month-old infants' expectations about where a person will search for a hidden object, as a function of the person's visual access to the location of that object. Of interest was whether infants would predict that a person who saw where a toy was hidden would subsequently look for the toy in that location. Together, these experiments sought to clarify whether infants appreciate that a person's visual experience influences her knowledge about objects, as demonstrated by her behavior.

The second paper further explored infants' understanding of the epistemic nature of eye gaze by examining whether infants' inferences based on eye gaze extend to any agent that displays looking behavior. Research suggests that by 18 months, infants use a person's visual access to make inferences about the person's knowledge for the location of an object, as demonstrated by the person's search behavior (Poulin-Dubois, Demke, & Olineck, 2007; Poulin-Dubois, Sodian, Metz, Tilden, & Schöppner, 2007). The second paper aimed to extend these findings by comparing infants' attributions of knowledge or ignorance, when looking behavior is displayed by a person or a humanoid robot. If infants understand that mental states are uniquely human, it was expected that they would respond differently when eye gaze is exhibited by human and nonhuman agents. Using the same preferential looking procedure designed in the first paper, we examined 18-month-olds' expectations about where an agent will search for a hidden object, as a function of the agent's visual access to the location of that object. Consistent with the first paper, we were interested in whether infants would make different predictions about the agent's search behavior as a function of her visual access or lack thereof. However, of primary interest to the second paper was whether infants would respond differently when the agent was non-human (i.e., a humanoid robot), compared to when the agent was a person. As such, this paper explored infants' concept of mentalistic agent, and examined whether their understanding of the relationship between eye gaze and knowledge holds when the agent is non-human.

In the third paper, infants' understanding of the epistemic nature of eye gaze was explored further within the context of a word learning task. Of critical interest was whether infants would use eye gaze to attribute referential intent to a human and a non-human speaker in a word learning context. As previous research has documented that infants readily use eye gaze cues to determine the correct referent of novel words when the speaker is a person (Baldwin, 1993, 1995), we were interested in examining whether 18-month-old infants would respond to eye gaze in the same way when it was exhibited by a non-human agent. Using a modified version of Baldwin's (1993) procedure, infants were exposed to either a human or robot speaker who uttered novel labels for unfamiliar objects under two different eye gaze conditions. Moreover, to further examine infants' concept of mentalist agent, we also explored whether infants would attribute referential intent to the robot speaker when an additional behavioral cue was added. It is well-documented that young infants often attribute goal-directed behavior to inanimate objects when the inanimate object displays contingent interaction (Johnson, 2000; Johnson et al., 1998; Shimizu & Johnson, 2004). Therefore, it is possible that infants' understanding of mentalistic agents is derived in part, from contingent interaction. To examine this possibility directly, in a third experiment infants were exposed to a one-minute contingent interaction between the experimenter and the robot, prior to commencing the word learning procedure. Of interest was whether the addition of contingent interaction would facilitate infants' attribution of referential intent to the robot speaker.

Taken together, the studies presented in this dissertation were designed to explore infants' understanding of visual perception and more specifically, whether infants understand that eye gaze is inherently associated with the formation of knowledge and that eye gaze reflects an individual's referential intent. Furthermore, findings from this dissertation provide insight into the nature of young children's concept of mentalistic agent during the second year of life.

Chapter 2

The inquisitive eye: Infants' implicit understanding that looking leads to knowing

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Contribution of Authors

This section documents the contributions of the second author in the paper entitled, "The inquisitive eye: Infants' implicit understanding that looking leads to knowing." The three experiments described in this paper each took place in the Cognitive Development Laboratory at Concordia University, Montreal.

Experiment 1 and 2 were conducted and analyzed by the first and third authors, and Experiment 3 was conducted and analyzed by the second author. To make the movies used in the procedure for Experiment 3, the second author videotaped two research assistants interacting with one another according to a script that was created by the second author. The second author edited the videotapes using the computer program imovie, and created Quicktime movies which were used as experimental stimuli. The second author also worked closely with a software programmer to develop a customized computer program that would enable the experimenter to present infants with two movies simultaneously on different computer monitors. The second author devised administration orders and programmed the movies into the computer software according to these orders.

The second author also drafted recruitment letters, consent forms and parent questionnaires that were used in the study (see Appendix A). The second author recruited English-speaking families by telephone while a research assistant recruited French-speaking families. A total of 27 participants were tested in this study; all infants were tested by the second author with the assistance of a research assistant. The second author also wrote letters to parents thanking them for their participation and informing them of the results.

A research assistant who was blind to the experimental conditions coded infants' looking time and a second assistant conducted inter-rater reliability tests on the coding. The second author entered the data from Experiment 3 into an SPSS spreadsheet and conducted the analyses. A research assistant ensured that the data entry was accurate.

Each of the authors contributed equally to writing this paper, which is published as a chapter entitled "The inquisitive eye: Infants' implicit understanding that looking leads to knowing" in the book edited by Flom, R., Lee, K., & Muir, D. (2007): *Gaze-following: Its Development and Significance*. Mahwah, NJ: Lawrence Earlbaum.

Abstract

A relatively large body of research has documented children's understanding of the causal linkage between visual perception and knowledge. In general, children below three years of age do not appear to appreciate that visual perception is necessary for knowledge acquisition. However, given the mounting evidence for implicit understanding of mental states in infancy, very young children might be able to grasp a more rudimentary understanding of the link between seeing and knowing. This chapter reports a series of experiments that assessed 14- to 30-month-olds' understanding of the link between visual perception and knowledge with tasks that employ non-verbal responses, such as toy choice and looking time. Overall, the findings indicate that by the age of 18 months, children distinguish between people on the basis of their access to perceptual information about a hiding event. However, this early distinction might not necessarily reflect a genuine understanding of the epistemic impact of seeing. The implications of these findings are discussed.

The inquisitive eye: Infants' implicit understanding that looking leads to knowing

Children's understanding of the significance of other people's eye gaze develops gradually. In particular, there are at least four critical levels of gaze sensitivity and understanding that can be traced (Povinelli & Eddy, 1996). At the first level, infants express a special sensitivity to eyes that is shared with many other species (see chapter 14, Flom et al., 2007). At the second level, which can be observed in the first few months of life, infants show a preference for eyes over other parts of the human face and engage with their caretakers in mutual gaze (Caron, Caron, Caldwell, & Weiss, 1973; Maurer & Barrera, 1981). By 3-6 months of age, infants progress to the third level of gaze sensitivity, and begin to engage in triadic interactions by shifting their gaze based on the other person's gaze direction. Gaze following becomes more robust and more accurate between 6 and 18 months of age. By the end of the first year of life, infants understand that there is some connection between the looker and the object of his or her gaze. This connection can take many forms, ranging from simple visual contact to predicting mental states, emotional reactions and other behaviors.

While the research supports this developmental progression, there is considerable controversy concerning the significance that researchers attribute to infants' gaze following. Proponents of a lean interpretation argue that gaze following is due to reinforcement, or that gaze following simply represents an innate orienting response (Langton et al., 2000; Moore, 1999). In contrast, proponents of a rich interpretation argue that gaze following provides evidence for infants' understanding of visual attention or perception (Carpenter, Nagell, & Tomasello, 1998). Infants' ability to link visual perception with other people's knowledge plays a critical role in their development of "theory of mind" (Flavell, 1999). In particular, children's appreciation of knowledge formation in themselves and others, including the causal role that perceptual access plays in the acquisition of knowledge, has been the source of considerable controversy. Research suggests that children seem to have developed some understanding of the link between perception and knowledge by 3 to 4 years of age. They understand, for example, that someone who has looked inside a container will know its contents, whereas someone who has not will be ignorant (Pillow, 1989; Povinelli & de Blois, 1992; Pratt & Bryant, 1990; Wimmer et al., 1988; Woolley & Wellman, 1993). Thus, they understand that visual perception and knowing tend to go together, even if they do not appreciate that perception is a necessary condition for knowledge (Perner, 1991). For example, preschoolers do not understand that one cannot gain information about the color of an object by touch alone, or that knowledge cannot be acquired when perception is entirely absent (O'Neill, Astington, & Flavell, 1992; Pillow, 1989; Ruffman & Olson, 1989).

Surprisingly, even with the use of more simplified procedures (similar to those used with non-human primates), researchers have been unable to detect an explicit understanding of the seeing-knowing relation prior to age three (Povinelli & de Blois, 1992). However, it remains unclear whether younger children may have a more rudimentary, or implicit, understanding of the link between seeing and knowing. Based on recent research, it is plausible to expect that an implicit understanding of the seeing-knowing relation might emerge prior to a more well-developed understanding that is verbally accessible. For example, toddlers' understanding of a story character's belief can be revealed by their anticipatory looking responses, even before they are able to explicitly demonstrate their understanding verbally (Clements & Perner, 1994).

Similarly, a study by O'Neill (1996) provided some indirect evidence that two-year-olds possess an implicit understanding of the seeing-knowing relation. In this study, 27- and 31-month-old infants made more frequent and explicit attempts to communicate with their mother when she was ignorant to the location of an object compared to when she was not. Moreover, a study by Dunham, Dunham, and O'Keefe (2000), which included additional methodological controls, revealed a difference between 28- and 33- month-olds' ability to take their parents' knowledge into account. In this study, infants in both age groups pointed more often to convey information to a parent who had not witnessed a hiding event, compared to a parent who had witnessed it. However, 33-month-olds were better able to adjust their behaviour depending on the parents' knowledge. Specifically, when a parent first covered his or her eyes but then reopened them during the placement of a sticker (i.e., peeking), the older infants considered the parent's new knowledge, and appropriately gestured less than when the parent did not peek. Together, these findings indicate that children possess an implicit understanding of the seeing-knowing relation by the end of the third year of life.

The series of studies presented in this chapter were designed to test the hypothesis that an implicit understanding of the link between visual experience and knowledge emerges *even earlier*, in the second year of life. This prediction is grounded in the observation that many of the building blocks necessary for an understanding of the association between vision and knowledge acquisition develop early, during the first year of life. As mentioned previously, attention to eyes or eye-like patterns appears very early in human development. Infants as young as 2 to 3 months show preferential attention to the eyes over other aspects of the human face, as well as an ability to follow the gaze of an adult when the target is within their immediate visual field (Caron et al., 1997; D'Entremont et al., 1997; Scaife & Bruner, 1975). Between 6 and 18 months, infants become both more likely to follow the gaze of another person and better able to turn correctly to objects outside their own visual field (Butterworth & Jarrett, 1991; Carpenter et al., 1998; Morissette, Ricard, & Gouin-Décarie, 1995). Of course, such behaviors may simply demonstrate that infants have learned that following another's eye gaze results in positive experiences, such as the sight of an attractive object (Butterworth & Jarrett, 1991; Moore & Corkum, 1998).

However, research on social referencing and attentional focus suggests that infants might also possess the more sophisticated understanding that visual perception corresponds to a subjective connection to the external world. In particular, toddlers understand that looking involves an attentional focus. For instance, they realize that a person will see an object if and only if the person's eyes are directed toward the object, and if her line of sight is not blocked by an obstacle (Flavell, 1992). Also, by 18 months of age, toddlers try to remove the hands covering their mother's eyes to show her a picture (Lempers, Flavell, & Flavell, 1977). Similarly, 18-month-olds are more likely to follow the gaze of an adult whose line of sight is unobstructed, than when it is obstructed, while 14-month-olds behave similarly across these contexts (Butler, Caron, & Brooks, 2000). Nonetheless, by 14 months of age infants are sensitive to the status of an adult's eyes, showing less joint attention behaviors when eyes are closed or when the adult wears a blindfold (Brooks & Meltzoff, 2002).

Other research suggests that the act of looking has a referential meaning for infants. For instance, studies on social referencing indicate that early in the second year of life infants use gaze to link emotional expressions to specific objects (Baldwin & Moses, 1994; Repacholi, 1998). Moreover, 16- to 18-month-old infants can use the eye gaze of a speaker to determine the correct referent of a new label, even when the object looked at and labeled by the speaker was different from the infant's attentional focus (Baldwin, 1991, 1995). Together, these studies provide evidence that between 12 and 18 months of age, infants begin to understand the attentional focus of another person as a psychological spotlight that can be intentionally directed at something in the environment.

Once infants are able to identify the referent of another person's attentional focus (i.e., they use eye gaze as a psychological spotlight), they progress to a more advanced understanding of looking, in which they are able to use this information to predict a person's subsequent behavior. In a recent study, Poulin-Dubois and colleagues (Poulin-Dubois, Sodian et al., 2007) examined whether 18- to 30-month-old infants recognize the relationship between a person's attentional focus and his or her behavior. To do this, infants were presented with videotaped events in which a person was shown looking and pointing at one of two objects. Each event was followed by the presentation of two still frames, each showing the actor grasping towards one of the two objects. The results showed that infants looked significantly longer at the incongruent behavior (i.e., actor grasping the object not looked at) than the congruent behavior (i.e., actor grasping the object looked at). This response suggested that infants expected the person to grasp the object that she had looked at previously and were surprised when the person reached for the previously ignored object. Recent studies using the habituation paradigm have demonstrated a similar understanding. For example, Woodward (2003) demonstrated that even younger infants understand that gaze involves a relation between a person and the object of her gaze. In this experiment, 7-, 9-, and 12-month-old infants were habituated to an actor repeatedly looking at one of two toys. Infants were then presented with test events in which the actor either looked at a different toy in the same location, or looked at the same toy in a different location. Overall, 7- and 9-month-old infants did not react when the object of the actor's attention changed (i.e., when the actor looked at a different toy in the same location); however, they were able to follow the actor's gaze to the toys. In contrast, 12-month-olds looked significantly longer at test events in which the object of the actor's attention changed (i.e., when the actor looked at a different toy in the same location) than at test events in which the location of the object changed (i.e., when the actor looked at the same toy in a different location). These results suggest that 12-month-olds, but not younger infants, expect a person who has looked at an object to subsequently act towards that object, and are surprised if this link is violated. Moreover, this finding has been replicated when eye gaze is paired with positive affect (Phillips, Wellman, & Spelke, 2002; Sodian & Thoermer, 2004).

In sum, the current review suggests that beginning around the age of one year, infants seem to attend to the relation between a person and the object of his or her gaze. More specifically, infants have some grasp that gaze direction can be used to predict people's behavior. However, the extent of infants' knowledge about the nature of this relation remains to be determined. In particular, it remains unclear whether infants are able to use eye gaze to make inferences about other people's knowledge. The following experiments represent a systematic attempt to shed light on this unresolved issue. In Experiment 1, we used an interactive search game, similar to the one used by Povinelli and deBlois (1992), to investigate whether infants understand that only the person who saw where an object was hidden will be able to help them find that object. In Experiments 2 and 3, a preferential looking procedure was designed to determine whether 18- to 24-month-old infants have some implicit understanding that seeing leads to knowing. Three-year-olds' anticipatory looking behavior suggests that they have a preliminary understanding of false belief even before they are able to make this understanding verbally explicit (Clements & Perner, 1994; Garnham & Ruffman, 2001). Therefore, we expected to observe a similar developmental pattern in infants' understanding of the seeing-knowing relation.

Experiment 1

In our laboratory, Bennett and Poulin-Dubois (1998) investigated whether 24- and 30-month-old infants possess an understanding that seeing allows another person to be "cognitively connected" to the world, and that seeing leads to knowing. The experiment was comprised of two tasks, and the order in which infants completed these tasks was counterbalanced.

Task 1. The goal of the first task was to examine 24- and 30-month-old infants' ability to recognize that responses to non-verbal communicative acts require that a person's eyes be unobstructed. As reviewed above, previous research has shown that by the end of the second year, infants understand that a person is able to see something only when the person's eyes are open. In order to ensure that infants understand the effect of a blindfold on visual access, a level-one perspective-taking task was administered (similar to the one used by Povinelli & Eddy, 1996). In the warm-up phase, infants were seated across from two actors who wore blindfolds around their necks, and were trained to touch the hand of an adult actor in order to retrieve a toy. The experimenter placed a toy in the middle of the table and asked the actors to each place one of their hands on either side of the infant. The experimenter then said "Let's play with the toy! Who can get the toy for you?" Infants were instructed to touch one of the actor's hands and if they were reluctant, the experimenter demonstrated how to retrieve the toy by touching one of the actor's hands herself. In the experimental phase, there were four trials in which one actor was blindfolded and the other wore a blindfold around her neck. Each trial began with one of the actors placing a blindfold around her eyes. In order to emphasize to the infant that one actor could see and the other actor could not, the experimenter waved and greeted each of the actors, and only the actor who could see responded. The experimenter then placed a toy in the middle of the table and asked each of the actors to place one of their hands on either side of the infant. Infants were asked to touch an actor's hand in order to retrieve the toy. The investigators predicted that, if infants have learned the importance of "seeing" by 2 years of age, they would preferentially enlist the help of the non-blindfolded actor in order to retrieve the toy.

The number of times the infant touched an actor's hand, as well as which actor's hand was touched, was coded for analyses. Only infants who touched an actor's hand in at least one trial were included in the final analyses ($N = 23$; 10 24-month-olds and 13 30-month-olds). If infants refused to touch the hand of an actor during one or more of the remaining trials, their response was coded as incorrect. In the first analyses, the dependent variable was the number of trials (out of 4) in which the infant touched the hand of the actor who could see (i.e., demonstrated an appropriate response). A planned comparison revealed no significant difference between the number of appropriate responses demonstrated by the 24-month-olds ($M = 2.00$, $SD = 1.05$) and the 30-month-olds ($M = 2.53$, $SD = 1.99$), $t(21) = -1.12$, *ns*. At first glance, these results seem to indicate that both 24- and 30-month-old infants have a relatively minimal understanding of the importance of the "seeing" relation to the world. However, it is likely that infants' performance on this task was negatively impacted by their unwillingness to touch the hands of the actors. Therefore, in subsequent analyses, the investigators examined the proportion of times the infants chose to touch the hand of the non-blindfolded actor out of the number of trials in which they actually touched an actor's hand. The analyses indicated that 24-month-old infants touched the hand of the "seeing" actor at a rate greater than expected by chance (62.50%), $t(9) = 1.90$, $p < 0.05$. Similarly, the 30-month-old infants also touched the hand of the "seeing" actor at a rate significantly different from chance (85.90%), $t(12) = 5.12$, $p < 0.05$. These results suggest that, when infants' response rate was taken into account, both age groups preferentially touched the hand of the "seeing" actor when attempting to retrieve a toy. Overall, these data confirm that infants as young as 24 months of age understand that people's eyes have to be unobstructed in order for them to be connected to the world, which is a prerequisite for understanding the seeing-knowing relation.

Task 2. The purpose of the second task was to determine whether 24- and 30-month-old infants are capable of making inferences regarding another person's knowledge, based on whether or not she could see (i.e., had visual access) during the presentation of critical information. This task was a modified version of the procedure used by Povinelli and deBlois (1992). In the warm-up phase, infants were asked to watch two actors, who wore blindfolds around their necks, hide a toy underneath one of three cups. The actor who hid the toy placed her hand on top of the cup containing the toy, while the other actor placed her hand on one of the remaining cups. The experimenter then asked the infant "Who has the toy? Where is the toy?" The actors pushed their respective cups forward, and the infant was told to find the toy by lifting up one of the cups. The purpose of the warm-up phase was to familiarize infants with the process of watching the actors select a cup and then deciding which actor may have correctly identified the cup containing the toy. In the experimental phase, there were four trials in which one actor's eyes were blindfolded during the hiding of the toy, while the other actor wore a blindfold around her neck. A screen was placed in front of the cups so that infants were unable to see where the toy was being hidden. Once the screen was in place, the experimenter showed a toy to the infant and pointed to the actors. It was emphasized to the infant that one actor could see and the other could not. Specifically, the experimenter said "hello" and waved at each actor. The actor who was not blindfolded waved back at the experimenter while the actor who was blindfolded did not wave back in return. The infant was then asked to watch the experimenter hide the toy. The actor who wore the blindfold around her neck saw where the toy was hidden, while the blindfolded actor did not. Once the toy was hidden, the experimenter removed the screen and the blindfolded actor removed her blindfold. Then the experimenter said "Watch them. They are going to find the toy." The actor who had visual access during the hiding of the toy put her hand on the correct cup, while the blindfolded actor put her hand on an incorrect cup. After a short delay, the actors pushed their selected cups forward, and the infants were asked to find the toy by lifting one of the two cups chosen by the actors. It was predicted that, if infants understand that seeing leads to knowing, they would choose the cup of the actor who had visual access (i.e., who could see) during the hiding of the toy. The accuracy of infants' responses was coded.

The results indicated that there was no significant difference between the number of trials in which 24-month-olds ($M = 1.72$, $SD = 1.07$) and 30-month-olds ($M = 1.96$, $SD = .88$) correctly chose the cup containing the toy, $t(50) = .403$, *ns*. Neither the 24-month-olds nor the 30-month-olds chose the correct cup at a rate greater than one would expect given chance alone (55.90% and 53.41%, respectively). Taken together, these results indicate that 24- and 30-month-old infants do not yet possess an understanding that seeing leads to knowing. However, it is possible that these results may be partially due to methodological constraints, such as the complexity of the task and the memory requirements. For instance, infants may not have paid adequate attention to which actor had visual access, and which actor did not have visual access during the hiding of the toy. Moreover, infants may have simply forgotten which actor was blindfolded during the hiding phase, as the blindfolded actor removed her blindfold before placing her hand on one of the cups. These methodological limitations led us to develop a preferential looking paradigm that would tap into infants' precocious ability to react to a violation of their expectancies.

Experiment 2

In a recent series of experiments conducted in collaboration with Beate Sodian and her colleagues, we tested the hypothesis that an implicit understanding of the link between visual experience and knowledge emerges in the second year of life (Poulin-Dubois, Sodian et al., 2007). Using the violation of expectancy paradigm, we examined infants' expectations about where a person will search for an object, based on that person's prior visual access to the hidden location of the object. We predicted that infants would expect a person who has seen a toy being hidden under a box to subsequently look for the toy in that location. This expectation would be violated if the person looked for the toy in a different location. In addition, we predicted that infants would have no expectation about where a person who did not see the toy being hidden would subsequently look for that toy.

To test these hypotheses, we presented videotaped scenarios to 18- (N=30) and 24-month-old infants (N=30) using the preferential looking paradigm. Infants sat facing two screens that displayed these scenarios, which differed in whether or not an actor was able to see the location of a hidden toy. Each scenario was divided into two phases. The first phase (information phase) was presented on one screen, and showed a female actor seated at a table, with two identical overturned buckets on each side of the table. A second female actor stood behind the main actor, looked straight ahead, and called the infant's attention by saying "Hi, we are going to play a game". In one condition, the second actor put a blindfold over the main actor's eyes (no visual access) and then lifted each of the buckets, one at a time, revealing a cup under one of the buckets. Meanwhile, the blindfolded actor remained silent and motionless throughout the uncovering of the buckets. In the second condition, the blindfold was placed over the main actor's mouth (visual access was maintained), and she leaned forward and looked at each bucket as it was lifted. In both conditions, after these actions were completed, the second actor walked off-screen while the main actor remained seated and removed her blindfold. Then, the voice of the second actor was heard from off-screen, asking the other actor to find a target object ("Hi Judy, Where is my cup?"). After a 1.5 second pause, during which both screens were blank, the test phase began. The test phase consisted of two still frames, which were presented simultaneously on the two screens for a duration of 10 seconds. One still image presented the main actor pointing at the bucket which contained the target object (correct action), and the other still frame presented her pointing at the other, empty bucket (incorrect action). Simultaneously, her voice was heard, saying "It's here."

Infants were administered two trials, one in the visual access condition and one in the no visual access condition. Across infants, the bucket under which the toy was located, presentation of the information phase (on left screen or right screen), and presentation of the correct action in the test phase (on left screen or right screen), was counterbalanced across trials. For each trial, the amount of time infants looked at the screen displaying the information phase, and the amount of time they looked at each of the two screens during the test phase was measured.

To ensure infants encoded all of the relevant information in each film, only infants who looked at the screen for at least 80% of the total duration of the information phase, and at least 25% of the total duration of the test phase were included in the final analyses (none were excluded on the basis of this criteria) Overall, 18- and 24-month-olds demonstrated the same pattern of behavior, as depicted in Figure 1. Analysis of variance revealed a significant interaction, whereby infants' responses to the correct and incorrect actions were different in the visual access and no visual access conditions. Pairwise comparisons revealed that infants looked significantly longer at the correct action when the actor's eyes were blindfolded ($M = 4.79$ s, $SD = 1.45$) compared to when

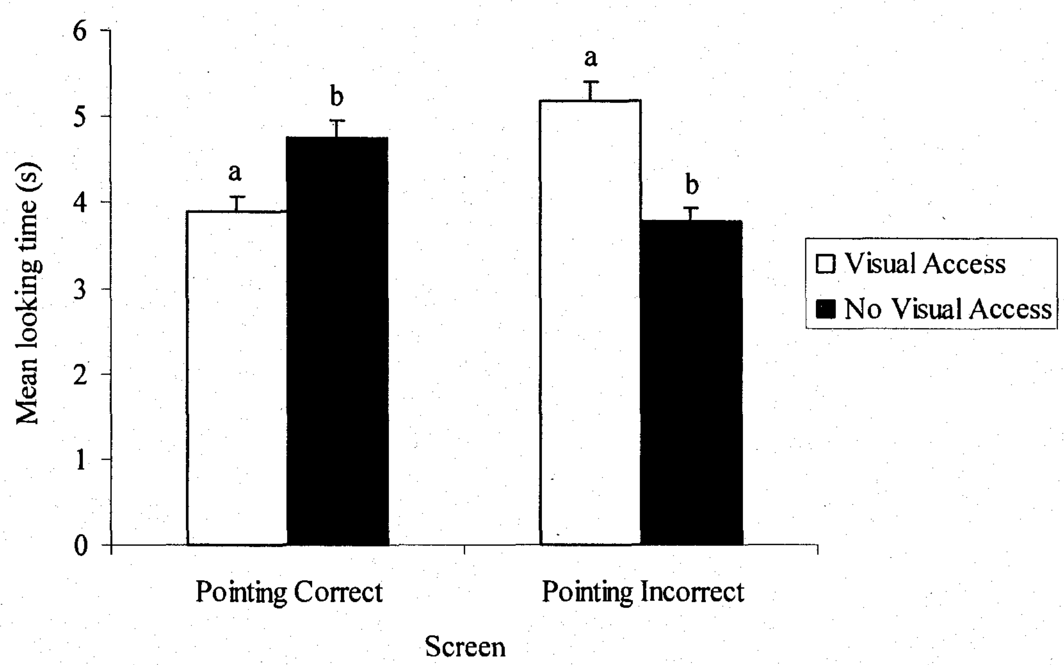

Figure 1. Mean looking time at the correct and incorrect actions as a function of visual access in Experiment 2. Note: bars labeled with the same letter differ significantly, $p < .05$.

she was able to see the event (*M* = 1.53 s, *SD* = 1.53). This indicates that infants were surprised to see the actor pointing to the correct location when she had not seen where the toy was hidden. In contrast, the opposite pattern was observed for the incorrect action. Infants looked longer at the incorrect action when the actor was able to see the event (*M* = 5.19 s, *SD* = 1.63) compared to when she was unable to see the event (*M* = 3.77 s, *SD* = 1.27). Thus, infants were surprised to see the actor pointing to the incorrect location when she had seen that the toy was hidden in a different location. To determine if infants looked differently at the actions within each condition (i.e., visual or no visual access), their looking times at the correct action were expressed as a ratio of their total looking times at both actions (expressed as a percentage), and compared to chance (50%). When the actor could not see the location of the hidden toy, infants of both ages looked longer at the correct action than expected by chance (*M* = 55.49%, $t(29) = 2.20$, $p < .05$ for 18-month-olds and *M* = 55.86%, $t(29) = 2.67$ for 24-month-olds, $p < .05$). When the actor was able to see the location of the hidden toy, 18-month-olds looked longer at the incorrect action than expected by chance (*M* = 59.86%, $t(29) = 4.11$, $p < .05$), whereas 24-month-olds looked at the incorrect action at chance levels (*M* = 54.30%, $t(29) = 1.39$, *ns*).

These findings suggest that at 18 months, infants expect that someone who saw the location of a hidden object will search for the object successfully, whereas someone who did not see the location of a hidden object will be unsuccessful. However, if the infants expected the blindfolded person to be ignorant, like adults, they should have expected the person to simply guess the location of the objects. Instead, infants seem to expect ignorance (i.e., no visual access) to lead to incorrect actions. Of course, an alternative interpretation is that infants simply computed an association between eye gaze and the object during the information phase, and therefore expected gaze and pointing to be associated with the object again in the test phase. Because it was not possible to compute such a correlation in the no visual access condition, infants could not predict where the actor would search, and were surprised to see the actor point at the correct location. The following experiment was designed in order to clarify the interpretation of these findings.

Experiment 3

In Experiment 3, we attempted to clarify the nature of infants' implicit understanding of the seeing-knowing relation, while controlling for the possibility that infants were responding on the basis of a simple association between looking and the object. Infants were tested using a similar procedure, except that two objects were hidden during the information phase. As a result, the correct or incorrect action in the test phase was dependent on which specific toy the second actor requested, rather than a simple "perseveration" of behavior towards any object available, as could have been the case in Experiment 2. We predicted that if infants' knowledge is not simply based on behavioral regularities (i.e., that seeing leads to correct search, and not seeing leads to an incorrect search), infants would expect a person who has seen where the target toy is hidden to look in the correct location, and would be surprised if that person looks in the wrong location. In contrast, we predicted that infants would have no clear expectation about where a person will look for a particular toy when they have not seen where it is hidden.

Eighteen-month-olds (N=27) were presented with videotaped scenarios using the preferential looking paradigm. See Appendix B for a diagram of the apparatus used to present infants with the videotaped scenarios and Appendix C for a sample of the instructions provided to parents during the testing session. The videotaped scenarios were based on those used in the previous experiment, and the actors in the films followed the same procedure, with one primary exception. In the information phase, a different object was revealed under each of the two buckets (e.g., ball, cup). As in the previous experiment, the second actor requested the target object from off-screen, using the appropriate label for the object (e.g., "I'm looking for my ball. Where is my ball?"). Again, the test phase consisted of two still frames presented simultaneously for 10 seconds. One still image presented the actor pointing at the bucket that contained the target object (correct action), and the other still frame presented her pointing at the bucket that contained the other object (incorrect action). Still frames from the movies presented to infants are presented in Appendix D.

In contrast to the previous experiment, infants were administered a total of four trials, using two different sets of objects (ball and cup; car and duck). Thus, each object was the target once. Each infant observed two trials where the actor had visual access to the location of the toy, and two where she did not have visual access. Across infants, the order of trials, target object, presentation of the information phase (on left screen or right screen), and presentation of the correct action in the test phase (on left screen or right screen), was counterbalanced across trials. As in the previous experiment, infants' visual fixation was measured for each trial. Because Experiment 2 consisted of two trials, infants' responses to the correct and incorrect actions were compared across the visual access and no visual access conditions in only the first two trials. Overall, there were no main effects or interactions, as shown in Figure 2 (See Appendix E for ANOVA source

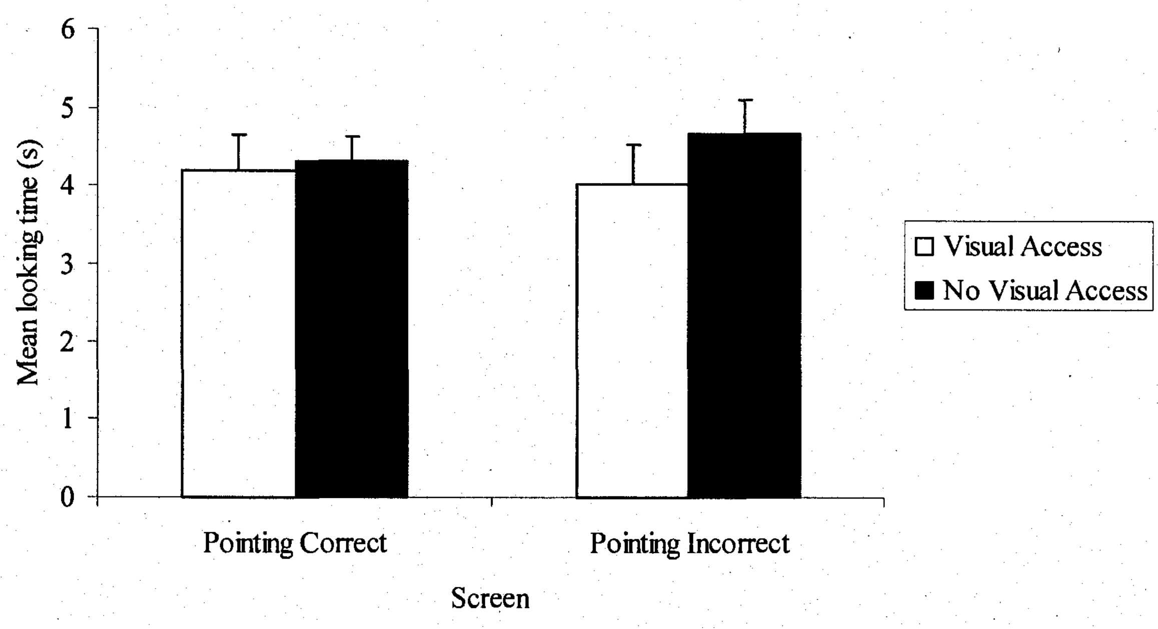

Figure 2. 18-month-olds' mean looking time at the correct and incorrect actions as a function of visual access in Experiment 3.

table). That is, there were no differences in infants' looking times at the correct and incorrect actions in the visual access condition (*M* = 4.21 s, *SD* = 1.73 and *M* = 4.03 s, *SD* = 1.77, respectively), or in the no visual access condition (*M* = 4.32 s, *SD* = 1.51 and *M* = 4.67 s, *SD* = 1.70, respectively).

Put simply, infants in Experiment 3 looked equally long at each action, across both the visual access and no visual access conditions. At first glance, this pattern of results is consistent with the lean interpretation of the data from Experiment 2, whereby infants expect that if a person looks at an object, their subsequent behavior will merely be directed toward that object. Of course, it is possible that these results may also reflect the inherent difficulty of the task. Recall that the identity of each of the objects, their locations, and the visual experience of the actor (i.e., visual access or no visual access) all had to be remembered during the test phase. Although familiar objects were used, they were only labeled by the actor in the test phase. Thus, infants were required to quickly identify each of the objects in the short period of time when the objects were revealed from underneath the buckets. In addition, while infants have sophisticated object permanence skills at this age, the use of videotaped scenarios likely made it more difficult for infants to track the location of the objects. Therefore, infants' memory constraints may have also contributed to these results.

Conclusions

Like many other primate species, human infants follow the gaze direction of others. Moreover, infants expect a person to see an object only under certain conditions. For example, they expect that a person must have her eyes open and aimed in the direction of the object, and her eye gaze must be unobstructed (Hare, Call, Bryan, &

Tomasello, 2000; Hare, Call, & Tomasello, 2001). Humans appear to have the unique ability to understand that eye gaze can be selective. In other words, humans recognize that people intentionally direct their eyes towards a particular object or person. Furthermore, only humans are able to understand that a person's visual experience influences their subsequent behaviors and beliefs about the world. By the end of the first year of life infants recognize that people are more likely to look at and touch an object that they have looked at before, compared to an object that they have ignored (Woodward, 2003). Impressively, infants continue to do so, even if the two objects have switched location (Woodward, 2003). Around the same age, infants also maintain the link between a looker and an object over time. For example, they understand that people are more likely to show excitement towards an object that they have never seen before, compared to familiar objects (Tomasello & Haberl, 2003). Despite these achievements, data from recent experimental studies (particularly those conducted with habituation or familiarization procedures) may simply provide information about infants' ability to understand behavioral propensities.

Little is known about infants' or toddlers' ability to grasp less tangible outcomes of visual attention, such as the seeing-knowing relation. To date, research has indicated that 3-year-olds have a basic knowledge of the link between seeing and knowing (Flavell, 1999). However, slightly younger children also appear to demonstrate this understanding within communicative contexts (Lee & Homer, 1999). The present series of experiments represent the first systematic attempt to examine infants' ability to use visual perception to conceptualize other people's knowledge. By using an interactive search game and the violation of expectancy paradigm, we were able to assess infants' understanding of the seeing-knowing relation via procedures that are less dependent on language and are therefore more infant friendly.

Taken together, results from the present series of experiments suggest that infants have reached a new stage of visual perception understanding by the middle of the second year of life. In particular, the results of the second experiment suggest that infants predict that someone who has seen the location of a hidden object will later search successfully when asked to find that object. Recall that in Experiment 2, infants looked longer when the actor's behavior was incongruous with their visual access. That is, infants looked longer when the actor saw where the object was hidden, and yet later pointed at the incorrect location. Also, infants were confused when the actor did not see where the object was hidden (i.e., was blindfolded), yet later pointed at the correct location. These looking patterns are striking given that infants were privy to the correct location of the object and therefore, may have been surprised to see the actor pointing at the incorrect location in both conditions. Instead, infants took the actor's visual experience into account and expected *different* behaviors as a function of that experience. We interpret these findings as evidence for the presence of an implicit understanding of the seeing-knowing relation by 18 months of age. However, we acknowledge that the results from Experiment 2 can be interpreted in a leaner fashion. That is, infants' looking time pattern may simply be attributed to rote expectations based on behavioral regularities (i.e., people point at objects they have just looked at). These two interpretations were directly examined in the third experiment, whereby infants were requested to find a specific object when *two objects* were hidden. We reasoned that if infants have an implicit grasp that seeing leads to knowing, the looking time pattern observed in Experiment 2 would be replicated. On the other hand, if infants were simply predicting that looking leads to subsequent looking and pointing behavior, infants would expect the actor who had visual access to two objects would point equally at both object locations, and they would be surprised to see the actor with no visual access pointing at any location.

Overall, the findings from Experiment 3 seem to support the leaner interpretation. Infants appear to understand that when a person looks at an object, they establish a long-term connection with that object, and are able to maintain the connection even if the object is no longer visible. However, the results of Experiment 3 may not provide conclusive evidence regarding the two competing hypotheses described above, because of the higher demands inherent in this task (e.g., greater memory load). In Experiment 3, infants had to keep track of the location of *each* object as well as the attentional state of the actor (i.e., seeing or not seeing) throughout the phase when the location of the hidden toys was revealed. Thus, it is possible that infants looked equally often at the two screens in the test phase because they could not recall the location of the target toy. This is in contrast with the task demands of Experiment 2, where only one object was hidden, making the location of that object very salient for the infant and presumably easier to recall. This potentially critical methodological limitation could be controlled for in future studies. One way to do this would be to label each toy as their location is revealed, while ensuring that no auditory cue is provided in the blindfolded condition (provide the labels with an off-camera voice). Another follow-up experiment that might clarify the nature of infants' ability to connect a looker with an object could be done using the present tasks, but eliminating all verbal information from the events. If the findings from Experiment 2 are replicated, this would confirm that the present patterns of results are based on behavioral regularities. The methodological limitations described above likely limit how conclusive our interpretations can be. However, we believe that we have been able to uncover a new step in infants' understanding of the link between looker and object. That new step involves an understanding that the connection between a looker and an object can be maintained even when the object is no longer visible, which corresponds to an implicit understanding that seeing leads to knowing.

The earliest age at which infants begin to understand the seeing-knowing relation remains to be determined. However, preliminary results from a recent follow-up study suggest that 14-month-olds do not seem to possess the same understanding as 18 month-olds (Metz, Sodian, & Poulin-Dubois, 2004). This follow-up experiment used the same procedure as outlined in Experiment 2, and the results showed that 14-month-old infants looked equally at both still frames in the test phase. Based on these findings, it appears that there is a developmental shift between 14 and 18 months, whereby infants' understanding of the connection between a looker and an object emerges. At first glance, this developmental effect seems to be consistent with other research showing important changes in the way infants reason about the cause of other people's behavior in general, and their understanding of visual perception in particular. For example, 18-month-olds, but not 14-month-olds, are more likely to follow an adult's gaze when her line of sight is unobstructed than when it is obstructed (Butler et al., 2000; Lempers et al., 1977). Also, between 12 and 18 months of age, infants develop an understanding of other people's intentions. Across these ages, infants perform better on the "failed intention" paradigm, and prefer to imitate intentional, rather than accidental, actions (Bellagamba & Tomasello, 1999; Olineck & Poulin-Dubois, 2005). Thus, the present pattern of results is consistent with the development of a cluster of other abilities reflecting infants' understanding of other people's behavior (Meltzoff, Gopnik, & Repacholi, 1999; Poulin-Dubois, 1999). The experiments described in this chapter suggest that 18-month-olds understand that if people have visual contact with an object, this perceptual experience will subsequently influence their actions toward that object, even if the object is out of sight. We believe that this is a more advanced understanding of the looker-object link observed in 12-month-olds (Woodward, 2003). This understanding is more sophisticated because it requires granting others with a form of object permanence. Moreover, this understanding is impressive because it is based on a single exposure to the visual experience of another person.

Future research is needed to address the precise nature of infants' connection between visual perception and other's epistemic and motivational states. One unresolved issue is whether infants appreciate that people's mental states are influenced by the quality of their perceptual connectedness to objects in the world. Adults and older children operate under the principle that a prolonged look at an object indicates that that particular object is more likely to be the actor's goal compared to an object that was either glanced at, or briefly touched by mistake (Montgomery, Bach, & Moran, 1998). In the present experiments, the actor looked desirously at one object (Experiment 2) and at two objects (Experiment 3). It remains to be determined whether a quick glance at one of the two objects would have had an impact on infants' performance. Recent research examining 14- and 18-month-olds' reenactment of intentional and accidental actions provides indirect evidence that by 18 months of age, infants are more likely to consider prolonged looking at and touching an object as markers of intentional action (Olineck &

Poulin-Dubois, 2005). For this reason, 18-month-olds may be more likely than 14-month-olds to imitate intentional compared to accidental actions (Olineck & Poulin-Dubois, 2005).

In conclusion, the foundation for infants' explicit understanding that seeing leads to knowing is established during the second year of life. During this time, infants gradually come to appreciate that people's eye gaze can be used to predict their future behaviors toward objects. Infants also appreciate that they can refer to another person's perceptual experience when making inferences about that person's mental state. For example, infants can use eye gaze information to evaluate a person's knowledge about the location of an object, and to infer whether the person has forged a long-lasting representation of that object. The transition from understanding eye gaze as a simple object-oriented behavior, to understanding eye gaze as a source of mental state knowledge is still not well documented. Furthermore, there is debate about how existing evidence for this ability should be interpreted. It remains to be determined whether infants understand other people's eye gaze in purely behavioral terms, or whether their understanding of eye gaze provides a foundation for their knowledge about people's mental states. It is also possible that infants develop these two abilities in parallel, and consequently they might represent two separate systems for detecting and interpreting intentions (Povinelli & Giambrone, 2001). With regard to gaze, we believe that the available evidence suggests that infants' gaze understanding develops from a low-level perceptually-based system to a higher-level inferentially-based system. In order to recognize the incongruity between the actor's search behavior and their prior visual contact with the object, infants had to draw an inference about the actor's knowledge about the object location. This understanding represents a crucial developmental bridge between understanding gaze as a “behaviorist” to understanding gaze as a “cognitive” psychologist.

Chapter 3

Do the eyes have it? Infants' attribution of knowledge to an inanimate looker

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Contribution of Authors

This section documents the contributions of the first author to the article entitled, "Do the eyes have it? Infants' attribution of knowledge to an inanimate looker." The experiment took place in the Cognitive Development Laboratory in the Centre for Research on Human Development at Concordia University, Montreal.

With respect to the computerized robot used during the procedure, the first author worked closely with a software engineer to develop a custom-designed program that enabled the experimenter to control the robot's movements from a laptop computer. To make the movies used in the procedure, the first author videotaped an assistant interacting with the robot or with a second assistant according to a script that was created by the first author. The first author operated the robot via the laptop computer during these interactions. Subsequently, the first author edited the videotapes using the computer program imovie™, and created Quicktime™ movies which were then programmed into the habituation software according to the administration orders that were devised by the first author.

With respect to data collection, the first author drafted recruitment letters, consent forms and parent questionnaires that were used in the study. The first author recruited English-speaking families by telephone and a research assistant recruited French-speaking families. A total of 55 participants were included in this study: 43 infants were tested by the first author and 12 infants were tested by a research assistant. When the research assistant completed testing, the first author was also present to observe the testing sessions and assist with the procedure. The first author also wrote letters to parents thanking them for their participation and informing them of the results.

A research assistant who was blind to the experimental conditions coded infants' looking time and a second assistant conducted inter-rater reliability tests on the coding. The first author entered data into an SPSS spreadsheet and conducted the analyses. A research assistant ensured that the data entry was accurate.

This paper was written by the first author and the second author offered comments and revisions. This paper has been submitted to *Cognitive Development* and is currently under review.

Abstract

Recent research suggests that infants become able to use eye gaze to make inferences about a person's knowledge during the second year of life. To further assess whether infants understand the *mentalistic* nature of seeing, the present experiment utilized a preferential looking paradigm to examine 18-month-olds' attributions of knowledge or ignorance when the agent is a person and when the agent is non-human. To provide a stringent test of infants' concept of mentalistic agent, the non-human agent was a humanoid robot that possessed distinctive facial features and displayed self-propelled motion and contingent interaction. Consistent with previous research, when the agent was a person, infants associated visual perception with correct search behavior. In contrast, infants did not demonstrate this expectation when the agent was a humanoid robot, despite the presence of salient animacy cues. The findings are discussed in terms of developmental changes in infants' concept of mental agent.

Do the eyes have it? Infants' attribution of knowledge to an inanimate looker

The eyes appear to play a pivotal role in infants' developing understanding of others. In the first few months of life, infants show a preference for eyes over other parts of the human face (Caron et al., 1997), and between 3 and 6 months of age, they begin to follow an adult's direction of eye gaze to objects within their visual field (D'Entremont et al., 1997). However, this behavior does not necessarily reflect an understanding of the mental experience of seeing, or an understanding of the functional role of eyes in this process. Rather, a conservative account would describe instances of early gaze following behavior as a reflexive shift of attention in response to an external cue provided by an adult's head turn (Moore, 1999). That is, early in the first year of life, gaze following behavior may simply demonstrate that infants have noticed the adult's head turn and reflexively moved their own head to the correct location in space without understanding anything about the adult's visual perception (Moore & Corkum, 1994).

By the end of the first year however, infants' gaze following ability has become more refined and evidence suggests that infants understand that eyes are critical for looking. For instance, 10- to 11-month-old infants are sensitive to the status of an adult's eyes, and follow gaze when an adult's eyes are open, but do not do so when an adult's eyes are closed (Brooks & Meltzoff, 2002; Meltzoff & Brooks, 2007). Slightly older infants have an even more developed understanding of the conditions necessary for visual perception. For example, 14-month-old infants are more likely to follow gaze when an adult's line of sight is unobstructed than when an adult's vision is obstructed by a blindfold or an opaque screen (Brooks & Meltzoff, 2002; Caron, Kiel, Dayton, & Butler, 2002; Dunphy-Lelii & Wellman, 2004).

By the end of the first year, infants also appear to appreciate that looking behavior reveals a person's focus of attention (i.e., they understand that perception is goal-directed). By 12 months of age, infants encode a relationship between a person's looking behavior and a specific target object on the basis of eye gaze cues alone (Phillips et al., 2002; Woodward, 2003). When additional cues are provided, slightly younger infants also demonstrate an understanding of the relation between the looker and the object. For example, when eye gaze cues are supplemented with grasping behavior (Woodward, 2003), and when the looker's head and eye turns are embedded within a sequence of variable actions with a common end result (Johnson, Ok, & Luo, 2007), 9-month-olds show that they appreciate this relationship. A recent experiment by Csibra and Volein (in press), provides further evidence for infants' emerging appreciation of the referential nature of eye gaze. Specifically, in this study, both 8- and 12-month-olds expected a person's gaze to be directed at a specific referent object and were surprised when a person looked at a location where there was no object. Thus, by the latter part of the first year, infants appear to appreciate that looking is intentional and is directed at particular objects.

Between 9 and 12 month of age, infants' understanding of the relationship between the looker and the object of her gaze becomes increasingly more robust. Several lines of research complement these findings and suggest that there is a developmental shift in infants' understanding of the referential nature of eye gaze, whereby it becomes increasingly more sophisticated over the course of the second year of life. For instance, by early in the second year, infants demonstrate level-1 perspective taking skills and understand that another person may see something that he or she does not see (Sodian, Thoermer, & Metz, 2007). At this age, infants also begin to use the looking behavior of an adult to inform their behavior. Using a barrier paradigm, Moll and Tomasello (2004) demonstrated that 12-month-olds will crawl or walk a short distance in order to identify what an adult is looking at behind an obstacle. Using the same barrier procedure, Chow and colleagues (Chow et al., in press) recently demonstrated that 14-month-olds were more likely to follow an adult's gaze behind an obstacle when the adult was a 'reliable' looker, than when their experience with the adult led them to believe that she was an 'unreliable' looker. Thus, these studies suggest that infants use the adults' eye gaze as a cue to the location of a hidden object, and will vary their search behavior differentially on the basis of eye gaze cues and as a function of their experience with the looker.

Other research suggests that infants begin to apply their understanding of the referential nature of eye gaze to other developmental tasks, such as understanding emotions and learning language. For instance, 14-month-olds use eye gaze to relate emotional expressions to specific objects (Repacholi, 1998), and 16- to 18-month-olds use eye gaze to determine the correct referent of an unfamiliar label (Baldwin, 1993, 1995). Thus, by the end of the first year of life, infants' understanding of looking is quite sophisticated. They understand that eyes provide the looker with visual access to the external world, that eyes in particular are critical for seeing, and that looking involves an attentional focus. Moreover, they understand that looking is referential and directed at specific external objects and events. Over the following months, infants' appreciation of the subjective, referential nature of eye gaze appears to become more robust and more sophisticated, as it plays an increasingly important role in their everyday interactions and other developmental achievements.

To further examine infants' understanding of eye gaze as it relates to their understanding of people, researchers have also investigated whether infants use gaze direction as a marker of a person's epistemic state. One way this question has been addressed is by examining whether infants appreciate that seeing affords the looker with unique knowledge; that is, whether infants can predict the effects of a person's past visual experience on their actions. In one such study, Onishi and Baillargeon (2005) used a violation of expectancy paradigm to examine whether infants would predict a person's actions on the basis of belief attributions. In this procedure, infants first watched an actor hide a toy in one of two locations. Next, a change of location occurred that was only witnessed by the infant. As a result of this change, the actor had either a true or false belief about the toy's location. The authors anticipated that if infants expected the actor to search for her toy on the basis of her belief about its location, rather than on the basis of its actual location, then they should look longer when that expectation was violated. Indeed, the authors suggest that the pattern of results demonstrate that 15-month-olds expected a person to search for a toy on the basis of her true or false belief about the toy's hiding place. Thus, the authors interpreted these findings as evidence that the infants predicted the person's behavior by taking her belief state into account. However, it is also possible that infants may have merely developed an association between the person, object, and location, or they may have used situational cues, such as the presence or absence of the person, to infer the person's subsequent behavior (Perner & Ruffman, 2005).

In a recent series of studies, Poulin-Dubois and colleagues (Poulin-Dubois, Sodian et al., 2007) examined infants' expectation about a person's search for a hidden object as a function of the person's prior visual experience, or lack thereof. Using the violation of expectancy paradigm and a forced-choice procedure based on the preferential looking paradigm, infants were exposed to videotaped events in which a person either did or did not witness where an object was located. This was followed by the presentation of two still frames that depicted the person pointing at the correct and incorrect location for the object. Thus, one still frame reflected the actor's knowledge for the location of the object while the other still frame reflected her ignorance. The authors expected that if infants understand that the actor had a visual experience that directly influences her behavior, they would look longer at the unexpected events: the person pointing at the incorrect location for the object when she had seen where it was located and the person pointing at the correct location for the object when she was unable to see where it was located.

Their results showed a developmental progression in infants' understanding of seeing: when eye gaze was paired with body orientation, the pattern of results suggested that 18-month-olds expected that someone who saw the location of a hidden object would search for that object successfully, whereas someone who did not see the location of that object would search unsuccessfully. Thus, the 18-month-olds' behavior suggests that they understand what others can and cannot see at a particular moment, and moreover, know that what others have seen influences their behavior. By 24 months of age, the infants inferred a person's search behavior as a function of their visual experience when eye gaze was the sole cue. In contrast to the older age groups, 14-month-olds did not discriminate between the person's search behaviors as a function of the person's prior visual experience. While further studies are needed to clearly elucidate infants' understanding of the link between visual perception and behavior, these studies suggest that there is a developmental shift between 14 and 18 months, where infants gradually come to appreciate that people's eye gaze can be used to predict their future behavior toward objects, and that they can refer to another person's perceptual experience to make inferences about that person's mental state.

The present review suggests that by 18 months, infants appreciate that eyes are critical for looking, that looking is intentional and directed at specific external objects and events, that another person's looking can be used to predict their behavior, and that looking results in the mental experience of seeing. The results by Onishi and Baillargeon (2005) and Poulin-Dubois and colleagues (Poulin-Dubois, Sodian et al., 2007) also reveal that between 14 and 18 months, infants become able to use eye gaze to make inferences about a person's knowledge. To further examine whether infants understand the mentalistic nature of seeing, researchers have also investigated infants' understanding of eye gaze when it is exhibited by non-human agents.

In the first study designed to examine the conditions under which infants would follow the gaze of a non-human agent, Johnson, Slaughter, and Carey (1998) presented 12- to 15-month-old infants with a novel object with or without facial features, that acted contingently (beeping noise and flashing light) or non-contingently (silent and motionless) to the infant's own behavior. After a brief familiarization phase during which infants were exposed to the object either reacting contingently to their own behavior or not, the object beeped once and turned to orient towards one of two targets placed on either side of the infant. Infants were found to follow the gaze of the object when it possessed facial-like features, or when it had interacted in a contingent manner with the infant (or both). In another condition, the authors compared infants' responses when an unfamiliar person took the place of the novel object. The results revealed that infants were no more likely to follow the gaze of a contingently interacting person than a contingently interacting novel object with facial features. Based on these results, the authors concluded that by 12 months of age, infants' concept of mentalistic or intentional agent is abstract and includes any object that displays animate-like features, most specifically, facial features and contingent interaction.

This study by Johnson and colleagues (Johnson et al., 1998) was followed by many others which examined infants' concept of mentalistic agent by investigating the conditions under which infants respond to inanimate agents. The majority of this research has focused on the attribution of goal-directed behavior and gaze following in young infants (Biro & Leslie, 2007; Csibra & Gergely, 1998; Johnson, Shimizu et al., 2007; Johnson et al., 1998; Kamewari et al., 2005; Kuhlmeier et al., 2003; Luo & Baillargeon, 2005; Shimizu & Johnson, 2004). Together, these studies suggest that in the first year of life, young infants appear to rely on behavioral cues (i.e., self-propelled motion, contingent interaction, and the ability to vary action to reach an end goal) and perceptual features (i.e., humanoid appearance) to attribute dispositional states. Other research has examined infants' concept of agent at a later age and on more sophisticated mind-reading skills, such as attributions of intent. In a classic study comparing human and non-human agents, Meltzoff (1995) showed that when 18-month-olds witnessed a person perform a failed/incomplete action, they subsequently inferred the person's goal and completed the target action, even though they had never seen the action completed in its entirety. The same infants, however, failed to do so after they observed a self-propelled mechanical device (i.e., a mechanical pincher) perform the same incomplete action. On the other hand, when the same procedure involved a non-human agent that possessed facial features, hands, self-propelled behavior, and displayed contingent interaction (i.e., a stuffed orangutan that was operated in a puppet-like fashion), 15-month-olds completed the target action and reproduced the non-human agent's intended goal despite never seeing the action completed by the agent (Johnson et al., 2001). It is possible that the presence of human-like features and behavioral cues may have enhanced the younger infants' ability to attribute mental states to a non-human agent. However, it is also possible that infants' concept of animate agent is initially broad and then becomes more refined with age. Similarly, with respect to gaze following, it is possible that in the first year of life, gaze following behavior may be elicited by a wide range of agents that possess animate features (e.g., eyes) and display specific behavioral cues (e.g., self-propelled motion). With increasing age, infants may be more selective in terms of gaze following behavior and making corresponding attributions of intent. However, before the developmental progression of infants' concept of mentalistic agent can be clearly elucidated, it is necessary to contrast infants' tendencies to make different mental state attributions on the basis of behavior that is exhibited by different agents under controlled conditions. To date, very few studies have employed humanoid non-human agents, and none have examined infants' attributions of belief in this context.

The present experiment takes a step in this direction and examines whether infants infer knowledge based on the eye gaze of any agent that displays looking behavior. Previous research suggests that by 18 months, infants use a person's visual access to make inferences about the person's knowledge for the location of an object, as shown by her search behavior. In light of these findings, the present study compares infants' attributions of knowledge or ignorance, when the agent is a person and when the agent is non-human (i.e., a humanoid robot). Using the procedure developed by Poulin-Dubois and colleagues, infants were exposed to videotaped events in which an agent (i.e., person or robot) either saw or did not see where an object was located. Subsequently, infants were presented with two still frames that depicted the agent's knowledge for the location of the object: the agent pointing at the correct location for the object and the agent pointing at the incorrect location. Consistent with previous research, if infants understand that the agent had a visual experience that afforded her with unique knowledge about the event, one would expect infants to look longer at the unexpected outcome, where the agent pointed at the incorrect location when she previously saw the location of the object. One would also expect that infants would look longer at the corresponding unexpected outcome, where the agent pointed at the correct location when she was previously unable to see the location of the object. The critical question addressed by the present study is whether infants would respond differently when the agent was non-human (i.e., a robot), compared to when the agent was a person. Moreover, as the non-human agent exhibits a rich array of humanoid features (i.e., symmetrical shape, rounded head, upright body, large round eyes, mouth, and arms) and behavioral cues (i.e., self-propelled motion, contingent interaction), this procedure provides a stringent test of infants' concept of mentalistic agent. If infants appreciate that a person's eye gaze can be used to predict her future behavior toward objects, and that this is not the case for a non-human agent, one would expect to see infants in the robot group respond randomly while infants in the person group would respond in a similar manner to previous studies. This pattern of results would lend credence to the hypothesis that during the second year of life, infants appreciate the mentalistic nature of seeing and understand that seeing affords people with unique visual experiences that impact their epistemic states, while non-humans are not afforded the same mentalistic qualities.

Method

Participants

A total of 55 18-month-olds participated in the present experiment. Additional infants were tested, but were excluded from the final analyses due to fussiness (n = 12), experimenter error/technical problems (n = 4), failure to meet the criteria for looking time in the information phase (n = 11), side bias in the test phase (n = 2), and parental interference (n = 3).

Infants were randomly assigned to a person or robot condition, which resulted in 28 infants in the person condition (mean age = 18.17 months, range = 17.26 to 19.23 months, 14 males and 14 females), and 27 infants in the robot condition (mean age = 18.31 months, range = 17.52 to 19.20 months, 11 males and 16 females). Participants were recruited from birth records provided by a government health agency in the Montreal area. Infants were predominantly from families whose primary language was English (43.6%), while some families' primary language was French (16.4%). Forty percent of infants' parents reported speaking another language in the home. Most parents (81%) reported that their child did not have experience with remote-controlled toys, such as cars, animals, or robots. A sample recruitment letter, parent consent form, and demographic questionnaire are provided in Appendix F.

Materials and Apparatus

A programmable robot (Model DKR 8000, Dr. Robot Inc.) was used in video clips of the non-human agent condition (see Figure 3). The robot stood 46cm tall and had two wheels on its base. The robot's head possessed two large eyes and a metal mouth, all of which were mobile. The robot wore a red t-shirt, had rigid arms, and spoke via digitized audio files of a female voice emitted from a built-in speaker on the robot. The robot was operated via wireless technology and a custom-designed program was used to control its head, eyes, mouth, movements, and speech using a laptop computer.

The apparatus included a three-sided panel (centre piece 91.5 cm high and 122 cm wide) that was attached at the front edge and sides of a table. A Macintosh G4 computer was used to control the experiment, and was connected to three different monitors. One monitor was used by the experimenter behind the panel, while two monitors were used to display images to the infants. The display monitors were placed so that the screens could be viewed by infants through two square cutouts in the panel (42 cm diagonal) and were positioned 37 cm apart. A video camera was used to record infants' visual fixation through a small hole in the panel (5 cm in diameter), 46 cm from the bottom edge of the panel, slightly above and directly in the middle of the two monitors. During testing the experimenter was seated behind the panel, out of the infant's view. Infants were seated facing the panel, either in an infant seat or on a parent's lap, about 62 cm from, and directly facing the middle of the two display monitors. When infants were seated in the infant seat, the parent was seated directly behind the child to avoid unintentionally cueing him or her.

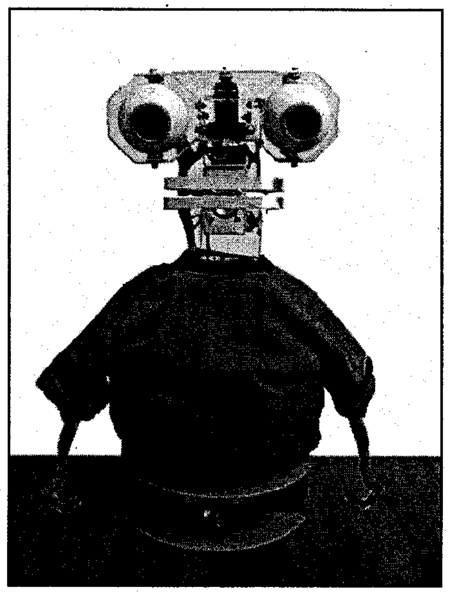


Figure 3. Humanoid robot.

Stimuli consisted of video clips (Quicktime™ movies) and still video frames that were presented on the two display monitors using the computer program Habit 2000 (Atkinson, 2000). Each movie depicted a videotaped script, which was presented on one of the two monitors, while the other screen remained black. In the person condition, the movies began with a female adult (Agent - Person) seated at a table on which two different colored buckets (red and green) were overturned and placed in front of her, one on each side of the table. A second female adult (Assistant) stood behind the Agent, looked straight ahead, and called the infant's attention by saying "Hi! We're going to play a game. Watch carefully!" In the eyes blindfolded condition, the Assistant put a blindfold over the Agent's eyes and then proceeded to lift each of the buckets, one at a time. This revealed a familiar object (cup, ball, car, or duck) under one of the buckets, while there was nothing located under the other bucket. When the Agent - Person was blindfolded, she remained silent and motionless, with her arms at her sides and her hands under the table, while the Assistant lifted each bucket. In the eyes open condition, the Assistant placed the blindfold over the Agent's mouth. Subsequently, the Agent - Person turned her head and looked intently at the location of each bucket as it was lifted. The movies for the robot condition were analogous to those for the person. Specifically, the robot (Agent – Robot) was seated in an infant seat at the table so its height was consistent with that of the Agent - Person. The role of the Assistant was identical in the person and robot movies. In the eyes blindfolded condition, the Assistant placed the blindfold over the robot's eyes, and the robot remained silent and motionless while the Assistant lifted each bucket. In the eyes open condition, the Assistant placed the blindfold over the robot's mouth, and the robot's head turned and its head and eyes bent downward so that the eyes were in line with the location under each bucket as it was lifted. The robot's arms were motionless and extended downward on each side of its body, analogous to the person's arms. For all movies, when the bucket containing the object was lifted, a female human voice was heard labeling the object from off-screen (e.g., "It's a *cup*. Look, it's a *cup*."). This verbalization was recorded and inserted into the movies using editing software and was added to facilitate infants' encoding of the identity of the object and its location. In all movies, after the above actions were completed, the Assistant loosened the blindfold so that it draped around the person/robot's neck and then walked off-screen. Subsequently, the Assistant's voice was heard from off-screen asking the Agent (person or robot) to find the target object (e.g., "I'm looking for my *cup*. Where is my *cup*?"). This scripted procedure comprised the information phase. All movies presented during the information phase for the person condition were 45 s in length, while all information phase movies for the robot condition were 51 s in length due to the robot's movements. The information phase was followed by a 1 s pause during which both monitors appeared black.

The test phase followed immediately after a 1 s pause, and featured two still images, which were presented simultaneously on the two monitors. In the person condition, one monitor presented the Agent - Person looking and pointing toward the bucket that contained the target object (correct action), and the other monitor presented her looking and pointing at the other, empty bucket (incorrect action). In the robot condition, the still images were analogous: the robot's head and eyes were directed toward the appropriate bucket, and its "arm" was extended toward that bucket as well. For both conditions the still images were presented simultaneously for 10 s. For coding purposes, the "ding" of a bell was inserted into the movies at the beginning of each information phase and the beginning of the test phase.

Procedure and Design

Participants were tested individually in a small testing room, and were seated either in an infant seat or on a parent's lap in front of the apparatus. Parents were instructed to look straight ahead, and to not interact with their infant in order to avoid unintentional cueing. Infants completed four trials, and each trial consisted of one information-test phase pair. The entire task lasted approximately five minutes. Infants completed this task with another laboratory task; about half of the infants completed this task first, while the remaining half completed this task immediately following the other.

Based on the procedure used by Poulin-Dubois and colleagues (Poulin-Dubois, Sodian et al., 2007), the preferential-looking paradigm was used to present infants with four videotaped movies that were divided into an information phase and a test phase as described above. For each infant, the information phase was displayed on the left monitor twice and on the right monitor twice. The order of presentation was determined using six semi-random orders so that the information phase did not appear on the same screen more than twice in a row. Within the information phase, the location of the hidden object (left bucket vs. right bucket), and identity of the hidden object (ball, car, cup, duck) were counterbalanced. Each object was the target once for each infant (i.e., once for each trial). For each trial, the adult always lifted the bucket on the seated person/robot's left side first. Thus, half of the time the hidden object was revealed under the first bucket that was lifted, while half of the time the hidden object was revealed under the second bucket that was lifted. With respect to the still images displayed in the test phase, the direction the person/robot was pointing (i.e., left, right) was counterbalanced across the monitors. Furthermore, the image displaying the person/robot pointing to the correct location of the toy was displayed equally often on the left and right monitors based on six semi-random orders, so that correct pointing was not displayed on the same monitor (left or right) more than twice in a row.

Each infant completed four trials:. two trials in the eyes open condition (EO) and two trials in the eyes blindfolded condition (EB). Six orders were used for presentation of EO and EB conditions, so that half of the infants saw an EO trial first, while the other half saw an EB trial first. Approximately half of the infants observed movies featuring the person ($n = 28$) while the other half observed movies featuring the robot ($n = 27$).

Coding

Videotaped sessions were coded by an independent observer who was blind to the location of the correct screen and agent condition. The amount of time (in seconds) that infants looked at each screen during the information phase and test phase was measured. A second independent observer recoded 20% of the videotapes. The mean Pearson product-moment correlation computed between the looking times obtained by the two observers was $r = .99$ (range = .99 to 1.00) across both phases.

Results

To ensure that infants encoded the events presented in the information phase, infants who looked at the screen an average of less than 80% across the four information phase trials were excluded from the final analyses (n = 11; 3 in the person group and 8 in the robot group). Furthermore, to ensure that infants encoded sufficient information in the test phase, infants' total looking time at both screens was required to be at least 25%

of the total duration of the test phase. All of the infants met this criterion. Two infants, one from each group, were excluded from the final analyses for exhibiting a side bias in the test phase, which was defined as looking at one screen (left or right) more than 65% of the time, across all test trials. Based on parent report, a subset of the infants (n = 17) had prior exposure to remote-controlled toys, such as cars, animals, or robots. As a result, a more conservative sub-sample was created by excluding these 17 infants, which resulted in a sub-sample of 38 infants (person condition n = 18, robot condition n = 20). All analyses were completed first using the original sample (N = 55; person condition n = 28, robot condition n = 27) and then using the sub-sample of infants who did not have prior exposure to remote-controlled toys (N = 38). Where the results are the same, the analyses using the original sample (N = 55) will be reported. Where the results are different, each sample will be discussed separately.

To determine if infants' looking behavior in the information phase varied across the two agent conditions, their looking times during the information phase were analyzed. Because the maximum possible looking time in each information phase trial was 45 s for the person condition and 51 s for the robot condition, the proportion of time infants spent looking at the screen in the information phase was expressed as a percentage. An initial analysis was conducted on infants' looking time during the information phase using a 2 (Condition: Eyes Open vs. Eyes Blindfolded) x 2 (Agent: person vs. robot) x 2 (Order: first trial is Eyes Open vs. first trial is Eyes Blindfolded) mixed model analysis of variance. The ANOVA revealed a significant three-way interaction between condition, agent, and order $F_{(1, 51)} = 4.77, p < .05$ (see Appendix G for ANOVA source table). Pairwise comparisons with a Bonferroni correction revealed that infants in the person condition looked longer at Eyes Blindfolded trials when the first trial was Eyes Open (*M* = 93.50%, *SD* = 4.74) than when the first trial was Eyes Blindfolded (*M* = 88.17%, *SD* = 7.62). This was not the case for infants in the robot condition. Of most importance, infants were quite attentive to both types of movies shown during the information phase (*M* = 89.87% for Eyes Open and *M* = 90.90% for Eyes Blindfolded).

For analyses involving the test phase, infants' total looking times at each of the two screens (correct action, incorrect action) was computed and averaged across the two trials in each condition (Eyes Open and Eyes Blindfolded). The maximum possible looking time per trial was 10 s. As preliminary analyses revealed no effects of Order, subsequent analyses of the test trial data were conducted without this variable. To examine whether infants looked longer at the unexpected actions in the Eyes Open and Eyes Blindfolded conditions, a 2 (Condition: Eyes Open vs. Eyes Blindfolded) x 2 (Screen: correct vs. incorrect action) x 2 (Agent: person vs. robot) mixed model analysis of variance was computed. The analysis revealed a significant interaction between condition and agent, $F_{(1, 53)} = 4.50, p < .05$ (see Appendix H for ANOVA source table). Pairwise comparisons with a Bonferroni correction revealed that infants in the robot condition looked longer at Eyes Blindfolded trials (*M* = 8.29 s) than Eyes Open trials (*M* = 7.54 s). Infants in the person condition did not exhibit this pattern. Thus, infants in the robot condition looked longer on trials when the robot was blindfolded than when the robot was not blindfolded, while infants in the person condition looked equally long at the eyes open and eyes blindfolded trial (see Figure 4). These results suggest that infants in the robot condition surmised that something was unusual about the blindfolded robot. There were no other significant effects or interactions.

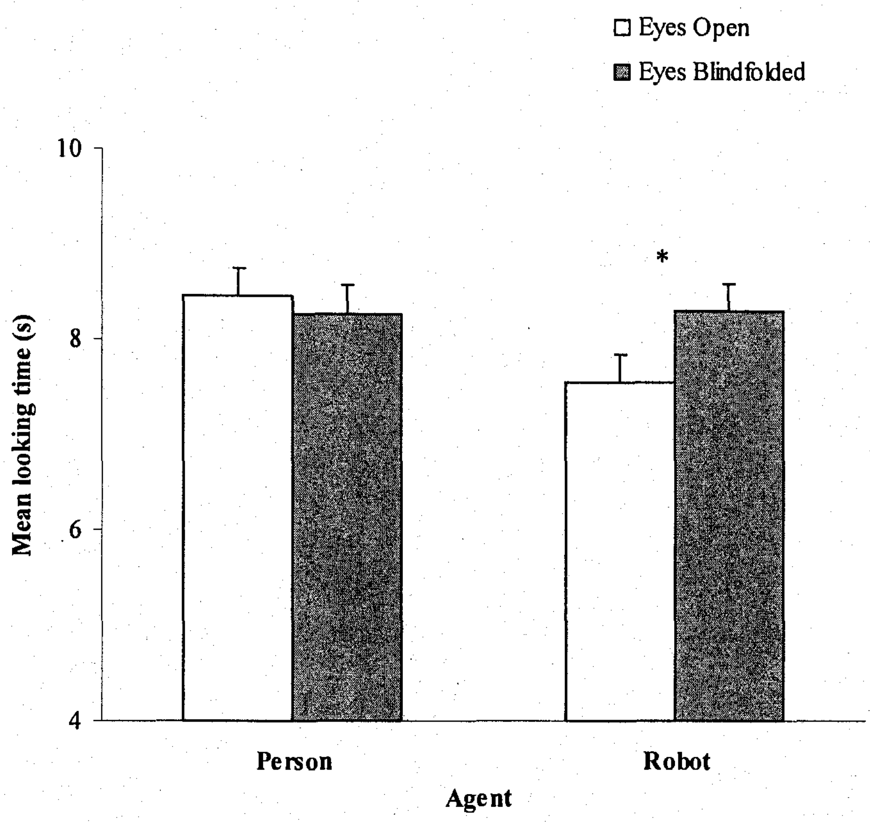


Figure 4. Mean looking time (in seconds) at eyes open and eyes blindfolded trials as a function of agent ($N = 55$). Note: asterisk indicates a significant difference, $p < .05$.

When the Condition (Eyes Open vs. Eyes Blindfolded) by Screen (correct vs. incorrect action) by Agent (person vs. robot) mixed model analysis of variance was repeated using the sub-sample of 38 infants, a different pattern emerged: in addition to a significant condition by agent interaction, ($F_{(1, 36)} = 3.91, p = .05$), there was also an interaction between screen and agent, $F_{(1, 36)} = 4.50, p \doteq .05$ (see Appendix I for ANOVA source table). To clarify the screen by agent interaction, pairwise comparisons with a Bonferroni correction revealed that infants in the person condition looked longer at the incorrect screen ($M = 9.02$ s) than infants did in the robot condition ($M = 7.48$ s). Thus, infants in the person condition looked longer at the screen that showed the agent pointing at the incorrect location for the toy, compared to children in the robot condition (see Figure 5).

To investigate infants' individual pattern of responses, nonparametric analyses were used to examine the number of infants who demonstrated the expected pattern and looked longer at the unexpected action in each condition, across the groups. Data from all four test trials was used. First, we examined the complete sample (N = 55). In the person group, Binomial tests indicated that the proportion of infants who looked at the incorrect action in the Eyes Open condition (64%) and the number of infants who looked at the correct action in the Eyes Blindfolded condition (50%) were not significantly above chance levels. In the robot group, Binomial tests indicated that the number of infants who looked at the incorrect action in the Eyes Open condition (52%) and the number of infants who looked at the correct action in the Eyes Blindfolded condition (59%) were not significantly above chance (50%).

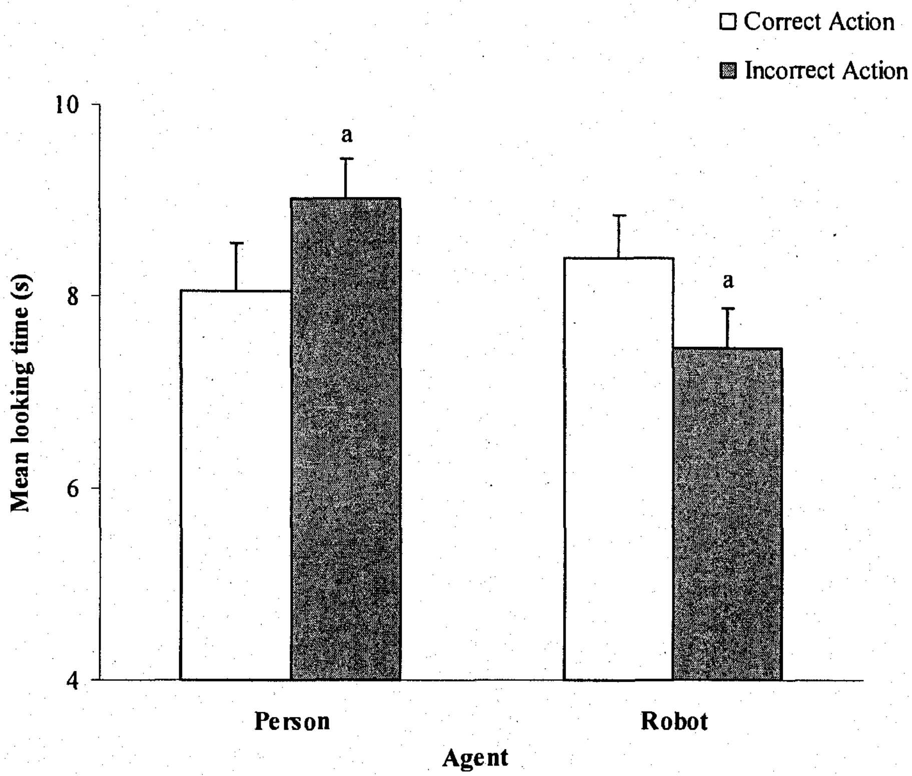


Figure 5. Mean looking time (in seconds) at the correct and incorrect action as a function of agent ($N = 38$). Note: bars labeled with the same letter differ significantly, $p < .05$.

hen these comparisons were completed using the sub-sample of 38 infants, the pattern of results was different: In the person group, Binomial tests revealed that the number of infants who looked at the incorrect action in the Eyes Open condition (72%) was significantly greater than chance (50%; $p < .05$), while the number of infants who looked at the correct action in the Eyes Blindfolded condition (39%) was not significantly above chance levels. In the robot group, Binomial tests indicated that the number of infants who looked at the incorrect action in the Eyes Open condition (55%) and the number of infants who looked at the correct action in the Eyes Blindfolded condition (65%) were not significantly greater than chance (50%). These results are consistent with the group data, where infants in the person condition were surprised to see the person who could see the location of the hidden toy, subsequently point to the incorrect location for the toy. Infants in the robot condition responded randomly.

Discussion

The present experiment was designed to clarify whether infants' inferences of knowledge based on perceptual access varied as a function of the agent that displayed the looking behavior. Previous research has shown that infants' ability to use a person's visual access to make inferences about the person's knowledge for the location of an object develops between 14 and 18 months of age (Poulin-Dubois, Demke et al., 2007; Poulin-Dubois, Sodian et al., 2007). The present study used the procedure designed by Poulin-Dubois and colleagues to compare infants' attributions of knowledge or ignorance when the agent was a person and when the agent was a humanoid robot. In the first phase of the experiment, infants were exposed to videotaped events in which an agent (i.e., person or robot) either saw or did not see where an object was located. Subsequently they were presented with two still frames that depicted the agent's belief about the location of the object: the agent pointing at the correct location for the object and the agent pointing at the incorrect location. Infants' looking time was measured as the dependent variable.

The present study tested two main hypotheses: first, if infants understand that the agent had a visual experience that affords her with unique knowledge, one would expect them to be surprised and look longer when the agent's behavior was incongruent with her knowledge. For instance, one would expect that infants would look longer when they saw the agent pointing at the incorrect location for an object when she had previously seen where it was. One would also expect that infants would look longer at the corresponding unexpected outcome, when they saw the agent pointing at the correct location for an object when she was previously unable to see where it was. Thus, we expected that infants in the person condition in particular, would respond in a consistent manner as the infants reported by Poulin-Dubois and colleagues (Poulin-Dubois, Sodian et al., 2007). Specifically, in that study, 18-month-olds responded differently depending on the visual access of the actor: they expected that a person who saw the location of a hidden object would search for the object successfully, whereas a person who did not see the location of the object would search for it unsuccessfully. In the present experiment, infants in the person condition looked longer at the screen that showed the agent pointing at the incorrect location for the toy, while they did not do so in the robot condition. Moreover, analysis of infants' individual pattern of results indicated that a significant proportion of infants in the Person Eyes Open condition demonstrated the expected pattern and looked longer at the unexpected action. Specifically, infants were surprised to see a person pointing to the incorrect location for an object, when she had previously seen where it was. In contrast, the majority of infants in the Person Eyes Blindfolded condition did not exhibit the expected pattern (i.e., Poulin-Dubois, Sodian et al., 2007).

Two subtle differences between the procedure used by Poulin-Dubois and colleagues (Poulin-Dubois, Sodian et al., 2007) and the current procedure, may account for the results obtained in the present study with regard to visual access. Specifically, in the present study, when the location of the object was revealed, infants heard a voice label the object from off-screen (e.g., "It's a *cup*. Look, it's a *cup*."). There was no such label provided in the Poulin-Dubois et al., procedure. We reasoned that providing infants with an additional cue to assist them in identifying the object would help them encode the location of the object and thereby potentially reduce the demands of the task. However, it is possible that in doing so, infants' attention was focused on the object at the expense of the agent, and at the expense of the status of the agent's eyes. Thus, focus on the object may explain why children tended to look at the incorrect location across both visual access conditions. Use of eye tracking technology would be necessary to directly examine this interpretation. Another possibility that may account for the findings obtained in the present study pertains to the gaze cues that were presented to infants. Specifically, it is possible that the eye gaze cues used in the present study were not sufficient for the infants to use eye gaze to infer the agent's subsequent behavior. It is important to recall that Poulin-Dubois and colleagues (Poulin-Dubois, Sodian et al., 2007) found a developmental effect in infants' understanding of seeing: 18-month-olds in that study were shown to understand the relationship between visual perception and behavior, when eye gaze and body orientation were provided as cues to the person's visual experience. However, these cues were not sufficient for 14-month-olds to demonstrate this understanding. In the present study, the only behavior cues provided to infants were eye and head movements. As such, it is plausible that the effect of visual access was reduced in the current study by the removal of other body orientation cues. Nonetheless, despite these differences, the proportion of infants who demonstrated the expected pattern lends credence to our hypothesis and suggests that the present findings are consistent with previous research: specifically, the majority of infants in the person condition who had no prior exposure to remote-controlled toys were surprised to see that a person would point to the incorrect location for an object, when she had previously seen where it was. Thus, infants expected that a person's visual experience provided her with unique knowledge that impacted her subsequent behavior.

The second hypothesis, and of utmost interest to the current study, was whether infants would respond differently when eye gaze was exhibited by two different agents: specifically, when the agent was a humanoid robot compared to when the agent was a person. If infants understand that a person's eye gaze can be used to predict future behavior toward objects, and that this is not the case for a non-human agent, one would expect infants in the robot group to respond randomly while infants in the person group would respond in a manner similar to previous studies. Some of the present findings suggest that infants in the present study treated the person and the robot agent differently.

First, infants in the robot group looked longer during the test trials when the robot was blindfolded compared to when the robot's eyes were unobstructed. Infants in the person group did not show this pattern. Thus, it appears that infants surmised that something was unusual about a blindfolded robot, while a blindfolded person was not unusual to them. It is possible that infants were simply surprised to see a blindfolded robot because they have never seen this occur before, while they have been exposed to a blindfolded person before, or some variant thereof (i.e., via peek-a-boo games). If this were the case however, we would also have observed a similar pattern during the information phase, which was not the case. Therefore, it seems that infants were surprised to see the blindfolded robot subsequently pointing, rather than simply the blindfolded robot. It is also possible that infants were surprised to see the blindfolded robot because they questioned the purpose of a blindfold for this type of agent. That is, a richer interpretation would propose that infants conceptualized the robot as an inanimate object, and therefore were surprised to see the robot's eyes blindfolded, as inanimate objects are not inherently capable of visual perception in the first place. Moreover, if infants treated the robot as an animate being, then one would expect that they would treat the robot and the person similarly, as younger infants have done in some studies (Johnson et al., 2001; Johnson et al., 1998). Therefore, at the very least, this finding is striking in that it suggests that infants clearly treated the person and the robot's gaze differently.

More convincing support for the possibility that infants conceptualized the robot as a different type of actor is evident in that infants anticipated a different type of relationship between the agent and the focus of its gaze, as a function of the identity of the agent. Specifically, only infants in the Person Eyes Open condition looked longer at the agent pointing to the incorrect location for the hidden toy, while infants in the robot condition responded randomly. That is, infants expected the person to search correctly, while they did not have the same expectation for the robot. Overall, infants appeared to appreciate that when a person sees an event, she has unique knowledge about the event, which ultimately impacts her behavior. They did not demonstrate this expectation when the agent was a humanoid robot.

Together, these findings add to the literature on infants' concept of mentalistic agent. On the one hand, some researchers propose that infants' attributions of intent are activated by an inherent mechanism that identifies an object as a psychological agent. This mechanism is proposed to operate based on sensitivity to behavioral motion cues, such as self-propulsion, contingent interaction, or the ability to vary action to reach an end goal (Csibra & Gergely, 1998; Gergely et al., 1995; Johnson, 2000; Leslie, 2000). Evidence where young infants attribute goal-directed behavior broadly to inanimate agents or follow the gaze of non-human agents lends support to this claim (e.g., Johnson et al., 1998). On the other hand, others propose that infants' understanding of intentional action is unique to humans and develops through experience with different types of agents (Meltzoff, 1995; Meltzoff & Brooks, 2001; Woodward, 2003; Woodward et al., 2001). Evidence that older infants (i.e., 18-month-olds) do not attribute goals to non-human agents (Meltzoff, 1995) lends support to this view. The current findings extend these results and suggest that when 18-month-olds observe a human and non-human agent exhibit the same looking behavior, they do not make attributions of knowledge equally to both types of agent. As such, these results support the notion that 18-month-olds' concept of mentalistic agent does not simply constitute any object that possesses animate-like features and displays contingent interaction. Importantly, as the non-human agent used in the present experiment possessed distinctive facial features and behavioral characteristics that are similar to humans (e.g., movable eyes, mouth, head, voice, self-propelled motion, contingent interaction), this task provides a stringent test of infants' interpretation of gaze and corresponding attributions of belief. These findings lend further support to the idea that infants' concept of mentalistic agent may narrow over the course of the second year.

Further research is warranted to clarify the precise nature of the developmental changes in infants' concept of agent, and to clearly elucidate the role of different physical features and behavioral characteristics that may play a role in infants' concept of intentional agent. Moreover, when examining infants' attributions of mental states to human and non-human agents, it would also be important to gather evidence pertaining to infants' attributions of a variety of mental states, such as knowledge/belief, desire and intention. If infants treat human and non-human agents differently, across a range of different mental states, this would provide stronger evidence for the claim that infants do indeed appreciate that humans possess mentalistic capabilities, while non-humans do not. In addition, a deeper understanding of the specific behavioral cues and features that infants use to make attributions of intent to human and non-human agents and how these may vary across age is of great interest. For instance, controlled studies that compare whether infants of different ages make mental state attributions when the same agents display specific features or motion characteristics, would provide valuable information about how infants' concept of mental agent may change with age. Further studies are also needed to clarify the relative importance of different cues and how they may be used differently by infants of different ages and in different contexts. Over time, it is critical that studies that examine these issues should employ a variety of methodologies and dependent variables (i.e., habituation, preferential looking, and interactive procedures). Only when findings converge across methods and measures will it be possible to make firm conclusions about the nature of young children's understanding of mental states and their concept of mentalistic agent.

Overall, the primary goal of the present study was to examine infants' concept of agent within the context of their understanding of the mentalistic nature of seeing. Specifically, we examined infants' attributions of belief when looking behavior was demonstrated by a human and non-human agent. The present findings extend the research in this field by demonstrating that infants did indeed treat the looking behavior of the person and the robot differently. Only infants in the person condition expected the agent to correctly point to the location for the hidden object when she had previously seen where it was, while they did not appear to have any specific expectation for the robot's behavior. Moreover, the present results suggest that by 18 months of age, infants are selective in their attributions of mental states and restrict attributions of goal-directed behavior to humans. These findings lend further support to the notion that infants' concept of mentalistic agent appears to narrow over the course of the second year. As such, the second year of life, and specifically, the period between 12- and 18-months of age, appears to represent a critical period in terms of how young children interpret the actions of human and non-human agents (Olineck & Poulin-Dubois, 2005; Poulin-Dubois, 1999; Repacholi & Gopnik, 1997). Future research in this realm holds exciting promise.

Chapter 4

Can infants use gaze direction to infer the referential intent of a non-human speaker?

Laura O'Connell, Diane Poulin-Dubois, Tamara Demke and Amanda Guay

Concordia University

Contribution of Authors

This section documents the contributions of the third author in the article entitled, "Can infants use gaze direction to infer the referential intent of a nonhuman speaker?" Each experiment in this paper took place in the Cognitive Development Laboratory at Concordia University, Montreal.

With respect to the computerized robot used in these studies, the third author worked closely with a software engineer to develop a program that enabled the experimenter to control the robot's movements and verbalizations from a laptop computer. The third author selected the present stimuli, created the test administration orders, and designed the procedure based on Baldwin (1993). The third author recruited and tested a total of 53 participants who participated in a pilot study. The third author also drafted recruitment letters, consent forms and parent questionnaires that were used in the present studies. Experiments 1 and 2 are included in the first author's M.A. thesis. All authors contributed to design, data collection, and analyses for the third experiment. The first, second, and third authors collaborated on writing this paper. This manuscript is currently under review for publication in the journal *Infancy*.

Abstract

Adopting a procedure developed with human speakers, we examined 18-month-old infants' ability to follow a nonhuman agent's gaze direction and subsequently to use its gaze to learn new words. When a programmable robot acted as the speaker (Experiment 1), infants followed its gaze toward the word referent whether or not it coincided with their own focus of attention, but failed to learn a new word in either case. When the speaker was human, infants correctly mapped words in both cases (Experiment 2). Furthermore, when the robot interacted contingently, this did not facilitate infants' word mapping (Experiment 3). While having eyes appears sufficient to elicit gaze following in 18-month-olds, it does not suffice for infants to attribute referential intent to a nonhuman speaker.

Can infants use gaze direction to infer the referential intent of a non-human speaker?

Gaze following occurs when a person looks to the location that another is looking. The ability to follow another person's line of sight holds significance for understanding the meaning of an emotional display (Moses, Baldwin, Rosicky, & Tidball, 2001; Repacholi, 1998), language acquisition (Baldwin, 1995; Bloom, 2002; Tomasello, 1995), and inferring a range of mental states such as intentions, beliefs, and desires (Baldwin & Moses, 1994; Lee, Eskritt, Symons, & Muir, 1998; Meltzoff & Brooks, 2001; Onishi & Baillargeon, 2005). Research on infants' ability to engage in gaze following has revealed that infants are able to follow a person's gaze direction to a highly visible object that is within their immediate visual field by 3 months of age (Caron et al., 1997; D'Entremont, 2000; D'Entremont et al., 1997). By 12 months, infants are able to achieve this same feat with targets outside of their visual field (Carpenter et al., 1998; Moll & Tomasello, 2004; Morissette et al., 1995). Despite the increasing number of studies available on infants' ability to follow gaze in different contexts, there is a lack of consensus concerning infants' interpretation of others' gaze (Flom et al., 2007). Specifically, there is uncertainty as to whether infants understand the act of seeing when they follow adults' gaze towards an object in the environment (Baron-Cohen, 1995; Bretherton, 1991; Caron et al., 2002; Carpenter et al., 1998), or whether infants' attention is drawn to a location due to an automatic orienting response or as a result of conditioning (Langton et al., 2000; Moore, 1999; Moore & Corkum, 1994; Povinelli, 2001).

In addition to being able to follow gaze, infants also construe looking as being a behavior directed at objects in the world around them. In the first study to investigate this ability, Poulin-Dubois (1999) showed 18- to 30-month-old infants videotaped events in which a person looked and pointed at one of two objects. Each event was followed by the presentation of two still frames that showed the actor grasping each of the two objects. Infants looked longer at the incongruent behavior (grasping the object not looked at) than the congruent behavior (grasping the object looked at). This response suggested that infants expected the person to grasp the object that she had looked at previously and alternatively, were surprised when the person reached for the previously ignored object. Using the habituation paradigm, even younger infants were found to demonstrate a similar understanding that gaze involves a relation between a person and the object of her gaze (Woodward, 2003). For instance, 7-, 9- and 12-month-old infants were habituated to an actor who repeatedly looked at one of two toys. To follow, infants saw test events whereby the actor either looked to the same location but at a different toy, or looked to the other location but at the same toy. Seven- and 9-month-olds did not react when the object of the actor's attention changed, although infants at both ages followed the actor's gaze to the toys. In contrast, 12-month-olds looked longer when the actor looked at a new toy in the same location, compared to when she looked at the same toy in a new location. Using the same procedure, where the actor grasped as well as looked at the toys, the younger infants were found to respond in a similar manner to the 12-month-olds (see also Phillips et al., 2002; Sodian & Thoermer, 2004 for similar results). Thus, these studies suggest that infants appear to understand the link between looker and object by the end of the first year.

Many theorists have proposed that word learning involves the understanding of the referential nature of the link between spoken words and the world (Akhtar & Tomasello, 2000; Baldwin, 1995; Tomasello, 2001; Woodward, 2004). Consistent with this notion, empirical evidence has shown that infants actively consult a speaker's gaze direction to determine the correct referent of a new word. Baldwin (1993) presented 13, 16, and 19-month-old infants with a novel word in one of two conditions. In the 'follow-in' condition, the novel label was produced while the speaker looked at a novel toy on which the child's attention was also focused. By contrast, in the 'discrepant' condition, the novel label was produced while the speaker looked at a second toy, while the child's attention continued to be focused on his/her own toy. Thirteen-month-old infants failed to make word mappings in either condition. In contrast, 16-month-olds made proper word mappings only in the follow-in, but not in the discrepant condition. Nonetheless, the 16-month-olds successfully avoided word mapping errors in the latter condition, suggesting that they were aware of the discrepancy between their own and the speaker's gaze. By 18 months, infants consistently linked the novel word with the object that the experimenter was attending to when she uttered the label, in both the follow-in and discrepant conditions.

If eye-gaze is a critical cue used by infants to establish word reference, perhaps the presence of gaze is sufficient for infants to infer referential intentions to any looker. Recently researchers have begun to investigate the cues that infants may use to attribute psychological properties to nonhuman agents. Specifically, infants' attributions of psychological properties to nonhuman agents has been examined using devices with human properties such as morphological features, self-propulsion, and the ability to interact contingently and reciprocally with another person (Johnson, 2000). For instance, Johnson, Slaughter, and Carey (Johnson et al., 1998) examined infants' gaze-following of a nonhuman agent by presenting 12- to 15-month-olds with a novel object with or without features that resembled a face and that acted contingently (beeping and flashing lights) or non-contingently (silent and motionless) with an experimenter. Infants followed the gaze of the object when its actions were contingent with the experimenter or when it possessed facial-like features. Based on these results, the authors concluded that infants over-attribute intentions to nonhuman agents, especially when such agents are found to interact contingently with another human. Much of the research on infants' concept of mentalistic or intentional agents has focused on the attribution of object-directed behavior and gaze following in very young infants (Biro & Leslie, 2007; Csibra & Gergely, 1998; Johnson et al., 1998; Kuhlmeier et al., 2003; Luo & Baillargeon, 2005). However, a few studies have also examined the scope of infants' concept of agent at a later age and on more advanced mind-reading skills, such as desire and intention. In one often-cited study, Meltzoff (1995) showed that at 18 months, infants who witnessed a human experimenter fail to complete a target action, subsequently inferred the intended goal of the experimenter and completed the unseen target action. Infants at this age, however, failed to do so after viewing a self-propelled, mechanical pincer attempt these same actions. Nonetheless, when the same procedure involved an autonomous, contingently interacting nonhuman agent that possessed morphological features (a stuffed orangutan toy), 15-month-olds, in fact, reproduced the agent's intended goal (Johnson et al., 2001). On the one hand, the presence of human-like features may have enhanced infants' tendency to attribute mental states to a non-human agent. On the other hand, it is also possible that, infants' concept of intentional agent might narrow and become more refined with age. For instance, one might predict that in the first year of life, gaze following might be elicited by a wide range of agents that posses animate properties (e.g., eyes), and with increasing age, infants might be more selective in terms of gaze-following behavior and corresponding attributions of intent. Before these developmental questions can be clearly addressed, it is of interest to contrast infants' tendency to make attributions of intent on the basis of gaze-following behavior exhibited by different agents under controlled conditions.

The main goal of the current study was to investigate 18-month-olds' concept of mentalistic agent via communicative intentions. Previous research reveals that 18-month-old infants actively seek a human speaker's gaze to learn the association between a novel label and its referent (Baldwin, 1993) and, at 12 months, will follow the gaze of a nonhuman agent (Johnson et al., 1998). In light of these findings, the current study examined, for the first time, whether young children would follow the gaze of a nonhuman agent (i.e. a robot), and if so, whether they are able to learn the label of an unfamiliar object. Using a modified version of Baldwin's (1993) procedure, 18-month-old infants were exposed to a speaker who uttered a novel label for an unfamiliar object under both a coordinated and discrepant gaze condition. In Experiment 1, labels were uttered by a small robot, and infants' comprehension of the novel labels was tested by a human experimenter. In Experiment 2, using the same procedure, labels were uttered by a human speaker, and a second experimenter tested infants' comprehension of the novel words. In the third experiment, another animate behavioral feature was added to the robot (contingency) to determine whether infants' interpreted the robot's gaze differently when this cue was present.

Experiment 1

Method

Participants

Twenty-nine infants approximately 18.5 months of age participated in the current study. Three infants were excluded due to fussiness, resulting in a final sample of 26 participants (mean age = 18.63 months, range = 17.95 to 19.75 months), with males and females being equally represented. Participants were recruited from birth lists provided by a governmental health services office. All infants were born full-term and had had no major health complications as reported by their parents. The children belonged to middle class families who spoke either French or English at home. A sample recruitment letter, parent consent form, and demographic questionnaire are provided in Appendix J.

Materials

All infants saw three pairs of familiar objects. A list of 18 familiar items was presented to parents prior to testing: *airplane, rabbit, bird, cat, doll, ball, sock, duck, car, shoe, spoon, flower, bottle, dog, banana, boat, cup,* and *keys.* Parents indicated which words their child understood, six of which were randomly selected by the experimenter to use for testing.

Infants were also presented with two pairs of novel objects during testing, as shown in Figure 6. The first novel toy pair included a colourful kaleidoscope and a wooden "nut-bolt" toy, while the second pair consisted of coloured wooden beads on a string and a blue cylindrical rattle. Novel toys were selected based on their novelty, attractiveness, manipulability, visual distinctiveness from one another, as well as equivalence in saliency.

Infants heard two novel labels during testing: *fep* and *dax.* These words adhere to the phonological rules of both French and English languages and were chosen based on

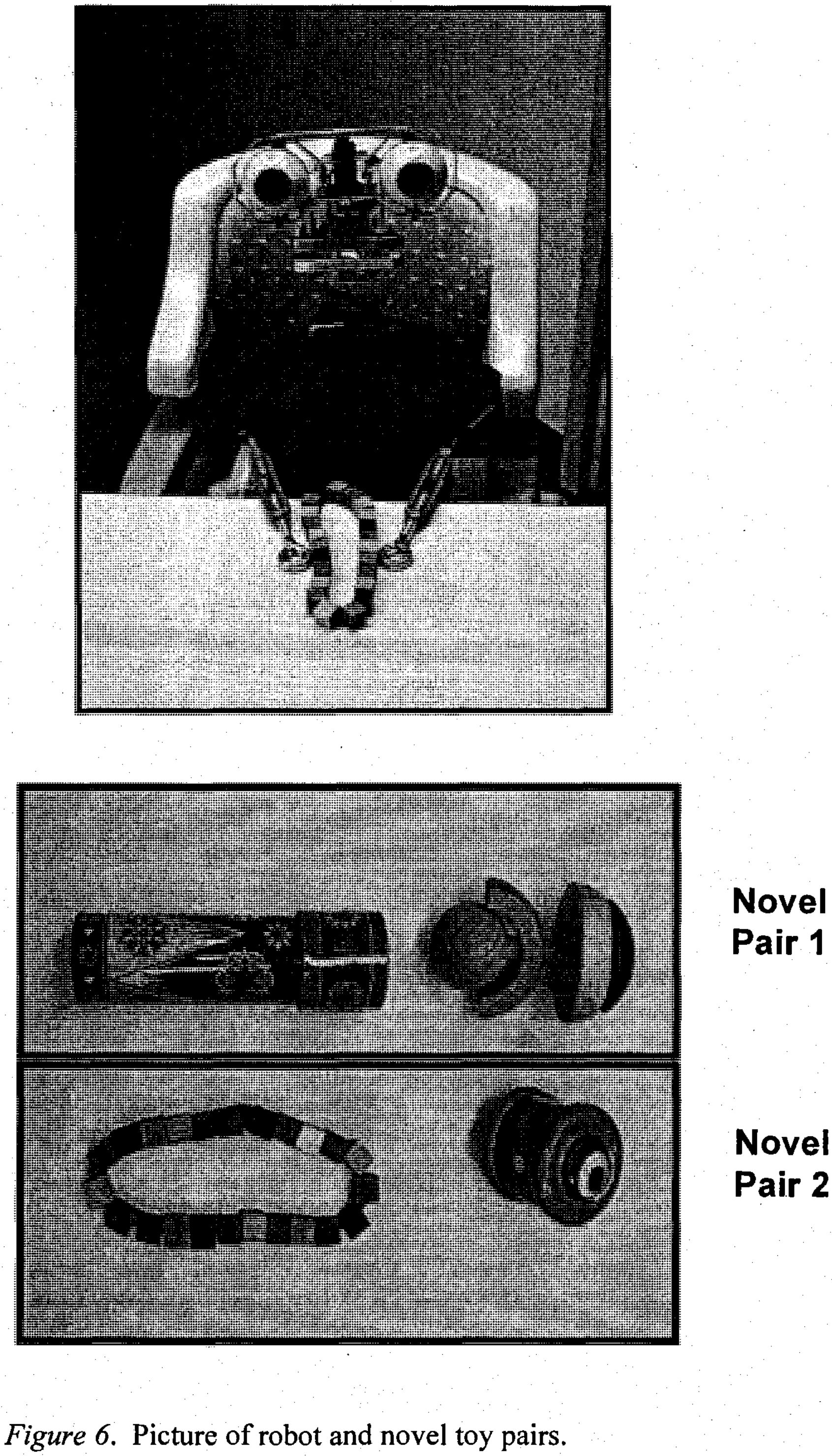


Figure 6. Picture of robot and novel toy pairs.

their novelty and ease of pronunciation for infants, as well as their distinctiveness from one another and from the familiar word items. The assignment of the novel words to the four novel objects was counterbalanced across infants.

A programmable robot (Dr. Robot Inc.) was used as the nonhuman speaker (see Figure 6). The robot stood 46 cm tall and had two wheels on its base allowing it to move around. Its head, mouth, and eyes were also movable. The robot wore a red shirt, had fixed arms, and spoke with a human voice that was emitted from a built-in speaker on the robot. The robot was operated via wireless technology and the experimenter controlled the head, eye, and mouth movements as well as the speech of the robot using a laptop computer. Three video cameras and a Hi-8 video cassette recorder were used to record the testing sessions.

Procedure and Design

Each infant participated in two conditions: *coordinated labeling (follow-in)* and *discrepant labeling*, which both included a *training phase* and a *testing phase*. During training, a novel label was repeated four times by the nonhuman speaker. As in Baldwin (1993), care was taken to ensure that the label was uttered at a time when the infant was attending to a novel toy previously given to him/her by the experimenter. In the coordinated labeling condition, the robot uttered the novel label when both child and robot were focused on the same novel toy (the child's toy). In contrast, during the discrepant labeling condition, the novel label was produced when the child and robot were each focused on a different toy.

In each condition, the training phase was immediately followed by a testing phase. To determine whether infants had correctly associated the novel word with its referent, a female experimenter presented infants with the novel toy pair and asked comprehension questions (i.e. "Where is the *dax*?"). Four trials were completed per word. Infants' understanding of familiar words was also examined to ensure their understanding of the experimental task and to maintain their interest. The same familiar toy pair was presented to the infants four times in each condition. Questions regarding novel words alternated with familiar word questions, for a total of eight comprehension test questions per condition.

The order of conditions, assignment of toy pairs, and labels for novel toys were counterbalanced across infants. More specifically, half of the infants were first exposed to the coordinated condition followed by the discrepant condition, while the other half was exposed to the conditions in reverse order. The order in which infants were presented with the novel toy pairs also alternated, such that half viewed the kaleidoscope and 'nut-bolt' toy in the first condition and then the rattle and cubes in the second condition. The other half of the infants were presented with the toy pairs in the opposite order. The labels assigned to the target toy in each condition alternated as well. That is, half of the children heard the word *dax* and then *fep* in the first and second conditions, respectively. In contrast, the other half of the infants heard the word *fep* in the first condition and then *dax* in the second. Over the course of the experiment each novel toy was selected as the target toy equally often. Finally, the target toys (novel and familiar) were positioned equally often on the right and left sides when they were presented to infants during testing.

Testing was conducted in either English or French, depending upon the child's mother-tongue, or in the case of bilingual children, the language that infants were most familiar with, based on parental report.

Families were greeted and shown to a reception room, where parents completed a consent form, a demographic form, and the familiar words checklist. During this time, the two experimenters played with the infant, allowing him/her to become comfortable with them. Next, infants were guided into the adjacent testing room where they were instructed to sit with their parent on a small stool positioned in front of the robot. At this time, one of the experimenters surreptitiously controlled the robot's movements using a laptop computer, while the other experimenter sat on the floor near the robot and directed the child's attention to it. During this *familiarization phase*, infants observed the robot move independently and vocalize (i.e., the robot turned its head from side to side, moved back and forth, and said 'hello' and 'oooh').

After the familiarization period with the robot, the first experimenter distracted the child with a toy, while the second experimenter moved the robot into a chair at the testing table. Careful measures were taken to ensure that infants did not see the robot being moved in order to avoid biasing infants' perceptions of the robot's animacy, as they had just observed the robot move on its own in the familiarization phase. During the testing phase, children either sat in a highchair attached to the testing table with their parent seated directly behind, or on their parent's lap. The first experimenter sat directly across the table from the child, while the robot was placed in another highchair to the left of the first experimenter.

Testing began with a *warm-up phase* whereby the experimenter produced a blue box holding two familiar items and shook it while placing it on the table in front of her. She then asked the child to identify one of the objects ("Where is the *car*? Can you find the *car*?") and pushed the box in front of the child. The experimenter applauded correct selections and corrected wrong choices.

Coordinated condition. The *training phase* began when the experimenter placed a box on the table, removed two novel toys from it, and placed them on the table out of the child's reach. She then demonstrated how to manipulate the toys, three times each, and gave them to the child to explore. Once the child had examined both toys and was focused on the novel toy pre-designated as his/her own, the experimenter placed the other novel toy on the table between the robot's hands. When the child was attending to his/her own toy, the experimenter initiated labeling by the robot using the laptop computer concealed under the table. In the *coordinated condition*, the robot then turned its head and looked at the child's toy while simultaneously uttering a novel label (e.g. "It's a *dax*!"). This was repeated four times, each time the experimenter ascertained that labeling occurred while the child's attention was focused on his/her own toy. At the time that the robot labeled the toy, the experimenter looked down so as to avoid eye contact with the child and unintentional cueing. After the fourth label, the robot's toy was returned to the infant to give him/her the opportunity to explore both toys again for a maximum of 60 seconds. Both novel toys were then removed from the child.

The training phase was immediately followed by a *testing phase*. Using the same novel toy pair and one familiar toy pair, infants' comprehension of novel and familiar labels was tested. The experimenter placed two toys, either familiar or novel, on a tray and positioned them on the table in front of her. She then encouraged the child to select a predetermined target toy by asking, "Where is the ____? Can you find the ____?" and then pushed the tray toward the child. The experimenter looked directly at the child to avoid biasing his/her selection. Regardless of the infant's choice, the experimenter asked, "Did you find it?" in a neutral tone. Then the toys were retrieved and the experimenter began the next trial. In alternating order, infants were asked four novel and four familiar toy questions, resulting in a total of eight trials. Infants who selected both toys simultaneously, or did not respond at all, were prompted once on each trial ("Can you give me the ___? Give Mommy the ___?"). Testing was discontinued if the child failed to respond on four trials in succession.

Discrepant condition. The discrepant *training phase* proceeded in the same manner as the coordinated condition with the exception that during labeling the robot was programmed to look down at its own toy, rather than at the child's toy. Additionally, a different novel toy pair and another novel label were used. The *testing phase* mirrored that of the coordinated condition, involving the novel toy pair used during training and a different familiar toy pair.

MacArthur Communicative Development Inventory (MCDI). At the end of each session, parents received the MDCI, a parent-report questionnaire designed to assess children's expressive vocabulary. Parents were asked to complete the questionnaire at home and return it to the research lab by mail.

Coding

Infants' behaviors were coded in terms of where they were looking during the training phase. As infants were looking at their own toy when the label was produced, our primary interest was where infants looked next, following hearing the label. More specifically, infant's looking direction was coded at the moment the novel label was uttered. Infant's head position and eye gaze were monitored to provide information as to infant's looking direction, to a maximum of three locations or targets, based on Baldwin (1993). Therefore, the infant's sequence of looks immediately upon hearing the novel label was recorded, to a total of three looks. In particular infants' looks were coded as directed at the speaker, the experimenter, the child's toy, the speaker's toy, and at their caregiver. Six infants (23%) were randomly selected to be coded twice, by two different researchers, who reached 100% agreement.

During the testing phase, infants' toy selection in response to each comprehension question was of primary importance. That is, infants' responses were coded with regards to which toy they touched first following each comprehension question. When two toys were touched simultaneously, the toy infants responded to after being prompted (e.g. "Can you give me the *dax*?") was considered. Six infants (23%) were coded independently by two coders, who were in 100% agreement.

Results and Discussion

Looks During Training

We first examined whether infants were attentive to the gaze direction of the nonhuman speaker during the training phase. Of interest was whether infants oriented to the robot at least once upon hearing the novel label. Out of four training trials, infants looked to the robot speaker equally often in the coordinated and discrepant condition, $t(25) = -0.40, p > .05$, suggesting that infants were attentive to the robot speaking in both conditions (see Table 1).

Table 1

Mean Number of Looks to the Robot, Infants' Toy, and Robot's Toy During Training in Experiment 1

	Condition	
	Coordinated	Discrepant
Looks to robot	3.62 (0.57)[a]	3.54 (0.76)
Looks to infant's own toy	1.27 (1.08)	0.77 (0.95)
Looks to robot's toy	1.04 (0.92)	1.50 (1.45)

[a] Standard deviation in parentheses

In Baldwin's (1993) study, 18-month-old infants followed the gaze of the human speaker, as evidenced by their tendency to look more often to their own toy in the coordinated condition as compared to the discrepant condition, and more frequently to the speaker's toy during the discrepant condition as compared to the coordinated condition. Analyses revealed a similar pattern of results in the current study (see Table 1). That is, after attending to the robot during labeling, infants looked to their own toy significantly more often during the coordinated condition than during the discrepant condition, $t(25) = -2.00$, $p = .05$. The pattern was similar, although less robust in the discrepant labeling condition. Specifically, infants' looks to the robot tended to be succeeded by a look to the robot's toy more often in the discrepant compared to the coordinated condition, although infants' responses failed to reach statistical significance, $t(25) = 1.85$, $p = .08$. Overall, the pattern of these results is consistent with the presence of gaze following in 18-month-olds, even in response to a nonhuman speaker. However, it remains unclear whether infants use the robot's eye gaze as a cue to determine the appropriate label for a novel object.

Comprehension Results

Familiar labels. In line with Baldwin's (1993) findings, infants performed at high levels in response to questions testing their comprehension of familiar items. More specifically, infants performed equally well in both conditions, such that they correctly selected the familiar target item 66.99% of the time ($SD = 28.43$) and 65.71% of the time ($SD = 28.99$) in the coordinated and discrepant conditions, respectively. In both conditions, these success rates exceeded chance levels (50%) (Coordinated: $t(25) = 3.05$, $p < .05$; Discrepant: $t(25) = 2.76$, $p < .05$).

Novel labels. If infants utilize the robot's social cues to correctly associate the novel label with the target of the speaker's gaze, one would expect them to select the robot's toy significantly more often in the discrepant as compared to the coordinated condition. Infants' success on novel label comprehension questions revealed a different pattern of responses across conditions, compared to familiar label trials. That is, infants selected the novel toy in the robot's possession during training at equal rates in both the coordinated ($M = 49.68\%$, $SD = 32.70$) and discrepant ($M = 50.64\%$, $SD = 35.51$) conditions, $t(25) = 0.11$, $p > .05$ (see Figure 7). In other words, infants selected the correct novel item only 49.68% and 50.64% of the time in the coordinated and discrepant conditions, respectively. Their success rates were not significantly greater than predicted by chance (50%) in either case (Coordinated, $t(25) = 0.05$, $p > .05$; Discrepant, $t(25) = 0.09$, $p > .05$). As such, these results indicate that 18-month-old infants failed to use the behavioral cues provided by the nonhuman speaker to learn the novel word. The above findings contrast with those reported by Baldwin (1993), where similarly aged infants selected the speaker's toy above chance levels in the discrepant, but not coordinated, condition when the speaker was human.

Overall, the results of Experiment 1 indicate that at 18 months of age, infants follow the gaze direction of a nonhuman speaker when hearing a novel label. However, infants' failure to associate the novel label with the object at which the nonhuman agent was gazing suggests that infants did not view such an agent as having the intention to name an object. That is, they failed to attribute referential intentions to the nonhuman speaker. When tested for their comprehension of familiar labels, infants selected the correct item at above chance levels, confirming that they understood the task at hand.

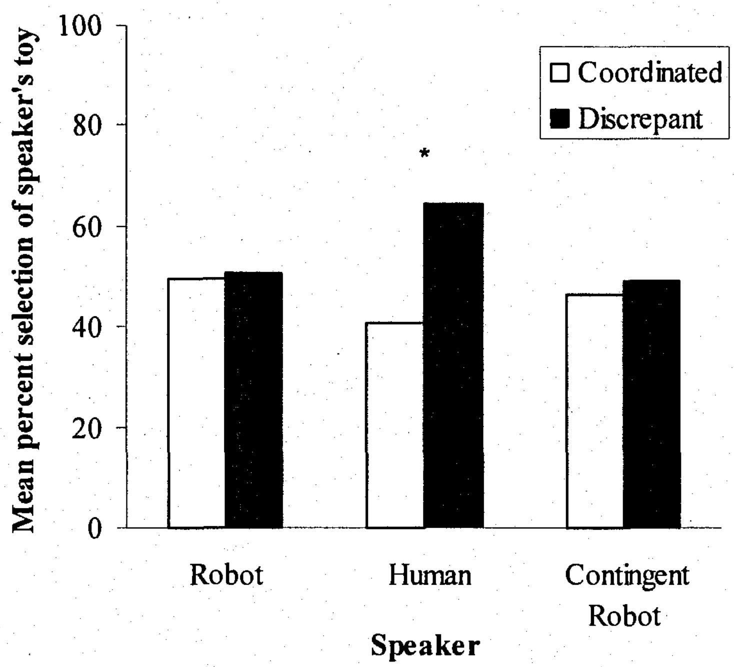


Figure 7. Mean percent selection of the speaker's toy in response to novel label comprehension questions in robot, human, and contingent robot speaker conditions. Note: asterisk indicates bars differ, $p < .05$.

Experiment 2

In Baldwin's original (1993) study, only one experimenter was present in the testing situation and was responsible for both training and testing of the child's word comprehension. However, in Experiment 1, two agents were present during testing: the experimenter and the robot, since the robot could not be programmed with the arm movements necessary to present the infants with toys. The presence of two agents during labeling may have confused the infants, as they may not have known which agent's gaze to follow. Likewise, infants may have consulted both the robot and the experimenter's gaze, each of whom looked in a different direction. That is, the robot looked to the appropriate object, while the experimenter looked down to her lap. To enable a direct comparison of infants' ability to follow a human and a nonhuman's gaze during word learning, a second experiment was conducted involving two human experimenters (speaker and tester). This additional investigation sought to determine whether the differences in results between human and robot conditions could be attributed to these methodological changes.

Method

Participants

Twenty-eight 18-month-old infants participated in the current experiment. The final sample consisted of 25 after three infants were excluded due to fussiness (mean age = 18.63 months; range = 17.79 to 19.56 months). There were 14 males and 11 females in the final sample. Participants were recruited in the same way as described in Experiment 1. All participants were full term at birth and were developing normally based on parental report. To ensure that age differences between infants in the experiments involving the robot and the human speaker would not account for any variations in performance, the mean age of both groups was compared. Infants in both studies did not differ in age, $t(50) = 0.00$, $p > .05$.

Materials

All stimuli and novel toy labels were identical to those used in Experiment 1. Two video cameras and a Hi-8 video cassette recorder were used to record the testing sessions.

Design and Procedure

The design and procedure were identical to Experiment 1, except that a second experimenter was present during testing and acted as the speaker during training. That is, two experimenters were involved, one being responsible for labeling and the other responsible for comprehension testing. As in Experiment 1, the first experimenter (tester) sat directly in front of the infant, with the second experimenter (speaker) to her left. The second experimenter placed her palms flat on the table and looked directly ahead at all times except during labeling. With the exception of each labeling of the novel toy, she remained completely silent and motionless. As in Experiment 1, during training, novel labels were uttered four times in each condition. Infants' comprehension of novel and familiar words were then tested in alternating order, four times each, resulting in a total of eight questions per condition.

Coding

Infants' behavior during the training and testing phase was coded in an identical manner to Experiment 1. All variables of six randomly selected infants were coded independently by two coders, who reached 100% agreement.

Results and Discussion

Looks During Training

Consistent with Experiment 1, infants oriented to the human speaker upon hearing the novel label in both conditions. More specifically, out of four training trials infants looked to the human speaker a mean of 3.72 times ($SD = 0.54$) during the coordinated condition and a mean of 3.48 times ($SD = 0.65$) in the discrepant condition, $t(24) = -1.81$), $p > .05$. Infants' looking behavior during training is presented in Table 2.

When examining infants' looking behavior following a look to the speaker during labeling, the same pattern of results emerged as in the previous experiment. After looking to the speaker, infants' mean number of looks to their own toy was significantly greater in the coordinated condition as compared to the discrepant condition, $t(24) = -4.42$, $p < .05$. In other words, infants attended to their own toy more often when the speaker had just labeled it, compared to when the speaker labeled her own toy. However, the reverse held true for infants' looks to the speaker's toy. That is, following a look to the speaker, infants looked to the speaker's toy significantly more often in the discrepant condition than in the coordinated condition, $t(24) = 4.70$, $p < .05$. These results suggest that infants were aware of the speaker's gaze-direction, demonstrated by the fact that they oriented more often toward the toy the speaker looked at when the novel label was produced, compared to the object that was not the target of the speaker's gaze.

Comprehension Results

Familiar labels. As expected, infants performed at high levels on familiar label comprehension questions. They performed equally well in both conditions, such that infants selected the correct familiar item an average of 67.00% ($SD = 31.59$) of the

Table 2

Mean Number of Looks to the Speaker, Infants' Toy, and Speaker's Toy During Training in Experiment 2

	Condition	
	Coordinated	Discrepant
Looks to speaker	3.72 (0.54)[a]	3.48 (0.65)
Looks to infant's own toy	1.68 (1.22)	0.60 (0.71)
Looks to speaker's toy	0.84 (1.03)	2.40 (1.16)

[a] Standard deviation in parentheses

time in the coordinated condition and 66.67% (*SD* = 29.46) of the time in the discrepant condition. In both cases, these rates exceeded chance levels (50%) (Coordinated: $t(24) = 2.69, p < .05$; Discrepant: $t(24) = 2.83, p < .05$).

Novel labels. An important difference between the previous and current experiment was uncovered upon analyzing infants' performance on novel label comprehension questions. That is, whereas infants failed to correctly associate the novel word with its referent when labeling was performed by a robot, infants succeeded in this task when the speaker was human. Infants selected the speaker's novel toy during training significantly more often in the discrepant condition ($M = 64.33\%$, $SD = 31.04$) than in the coordinated condition ($M = 41.00\%$, $SD = 33.84$), $t(24) = 2.72, p < .05$ (see Figure 7). Infants selected the correct novel item at above chance levels (50%) in the discrepant condition (64.33%), $t(24) = 2.31, p < .05$. In contrast, while infants tended to select the correct novel item in the coordinated condition (59.00%), their tendency to do so was not statistically greater than chance, $t(24) = 1.33, p = .09$.

MacArthur Communicative Development Inventory (MCDI)

Because infants' performance on this task could be affected by their verbal skills, an independent samples t-test was conducted to determine whether the vocabulary of infants in the robot and person conditions differed. Upon analysis, a significant difference was obtained (Experiment 1, mean number of words = 78.05, *SD* = 85.41; Experiment 2, mean number of words = 169.37, *SD* = 168.22), $t(36) = -2.11, p < .05$, such that, infants in Experiment 2 had a larger vocabulary score than infants in Experiment 1. This finding raised the possibility that infants in Experiment 2 succeeded in the word learning task as a result of more advanced verbal skills. To directly examine this question, two sub-samples were created by excluding infants whose vocabulary scores were considered outliers: four infants with the lowest vocabulary scores in Experiment 1 and four infants with the highest vocabulary scores in Experiment 2 were excluded. After eliminating these outliers, no significant difference in vocabulary size was found between infants in Experiments 1 and 2 (Experiment 1, $M = 96.00$, $SD = 87.93$; Experiment 2, $M = 93.80$, $SD = 82.42$), $t(28) = 0.71$, $p > .05$. Using these new samples, infants' performance on the novel label comprehension trials was compared in both experiments. Consistent with the previous analyses, infants in Experiment 1 selected the robot's toy equally as often in the discrepant condition ($M = 53.00$, $SD = 33.68$) compared to the coordinated condition ($M = 43.94$, $SD = 32.04$), $t(21) = 1.06$, $p > .05$. Also consistent with previous analyses, infants in Experiment 2 selected the speaker's toy significantly more often in the discrepant condition ($M = 65.87$, $SD = 30.49$) than in the coordinated condition ($M = 45.24$, $SD = 34.21$), $t(20) = 2.22$, $p < .05$. In other words, even after accounting for vocabulary size, infants who were trained by a nonhuman speaker failed to learn the new label, whereas those trained by a human speaker successfully learned the correct novel label. These findings confirm that the discrepancy between infants' word-learning abilities in the robot task as compared to the person task was not a result of differences in verbal skills between the two groups.

Gaze Following

Regardless of the animacy of the speaker, in response to hearing a new label, infants in both experiments shifted their gaze to locate the focus of speaker's gaze. Nonetheless, a notable difference was observed regarding the extent to which infants engaged in this gaze following behavior. Specifically, infants in Experiment 1 looked to the robot's toy a mean number of 1.50 trials out of 4 ($SD = 1.45$) in the discrepant training condition, a value significantly smaller than infants in Experiment 2, who looked to the speaker's toy a mean number of 2.40 trials out of 4 ($SD = 1.16$), $t(49) = -2.45, p < .05$. Alternatively, the extent to which infants followed the speaker's (robot or human) gaze during the coordinated condition did not differ across experiments (Experiment 1, Mean number of trials = 1.27, $SD = 1.08$; Experiment 2, Mean number of trials = 1.68, $SD = 1.22$; $t(49) = -1.28, p > .05$).

To further examine the relatively lower level of gaze following in the case of a nonhuman agent, additional analyses were conducted to determine infants' pattern of looking behavior. Infants' looking behavior was combined across conditions (a total of 8 trials). The extent to which infants looked to the experimenter during labeling trials did not differ between the robot and human groups (Experiment 1, Mean number of trials = 3.81, $SD = 2.26$; Experiment 2, Mean number of trials = 2.88, $SD = 1.86$), $t(49) = 1.60, p > .05$). However, infants in Experiment 1 looked to their caregiver more often immediately after hearing the novel label than did infants in Experiment 2 ($M = 2.73$, $SD = 1.66$ and $M = 1.44$, $SD = 1.26$), respectively $t(49) = 3.11, p < .05$. These findings suggest that upon hearing the robot's utterance, infants in Experiment 1 tended to orient to their caregiver for either social referencing purposes or due to surprise upon hearing the robot speak. Thus, the lower number of trials in which infants in Experiment 1 looked to the robot's toy during training can be explained by their increased tendency to engage in social referencing behavior upon hearing the speaker talk.

In sum, the results of Experiment 2 indicate that infants performed differently on the word-learning task in comparison to infants of the same age who were presented novel words by a nonhuman speaker in Experiment 1. Since the only methodological difference between the two experiments was the animacy of the speaker, we can conclude that infants' failure to map words to objects in Experiment 1 cannot be accounted for solely by our modifications to the original procedure, notably, the presence of two experimenters instead of one. This replicates previous findings of word mapping where the speaker's direction of eye gaze was used as a cue for determining the speaker's intent. As such, these results confirm that by 18 months of age, infants learn words by taking into account the referential intent of the human speaker.

Experiment 3

In Experiment 1, the robot was self-propelled and displayed morphological features consistent with animate objects. However, for 18-month-olds, these cues were insufficient for infants to attribute referential intent to the nonhuman agent. One might argue that the presence of other animate cues might have elicited such attributions. Research recently undertaken by Arita and colleagues (Arita, Hiraki, Kanda, & Ishiguro, 2005) found that 10-month-old infants were less surprised to witness an interaction between an experimenter and a humanoid robot if they had previously viewed a video recording of the humanoid robot engaging contingently with a human. Similarly, Shimizu and Johnson (2004) concluded that12-month-old infants viewed the behavior of an ambiguous object as goal-directed after viewing this object interacting with a human in a contingent manner, but not when this previous interaction was absent. These data indicate that at a young age, infants' understanding of an inanimate being as acting intentionally might be derived in part from contingent interaction. To our knowledge, only one study has examined the role of contingency in older infants' reactions to nonhuman agents. Dunham, Dunham, Tran, and Akhtar (1991) examined the role of a reciprocating social partner in facilitating conversation with 2-year-olds. They found that a robot whose verbalizations corresponded to the children's actions and speech stimulated social conversation in the young children to a greater extent than a robot who engaged in the same script, but without a reciprocal interaction that was contingent with the children's comments. There is a possibility then that 18-month-olds' word learning from a nonhuman speaker may be facilitated if infants viewed a contingent interaction between the robot and a human, prior to engaging in the testing procedure. To examine this possibility, we conducted a third experiment and added a one minute contingent interaction between the robot and the experimenter before infants commenced the word learning task.

Method

Participants

Thirty-seven 18.5-month-old infants took part in Experiment 3. Nine infants were excluded on the basis of fussiness ($n = 2$), not having French or English as a first language ($n = 2$), experimenter error/technical difficulties ($n = 4$), and poor attention during the interaction ($n = 1$). The final sample consisted of 28 participants (19 males, 9 females) with a mean age of 18.50 months, ranging from 17.59 to 19.69 months. The mean age of infants in the current experiment did not differ significantly from that of infants in Experiment 1 ($t(52) = 0.99, p > .05$) or Experiment 2 ($t(51) = 1.34, p > .05$). Given that male participants largely outweighed female participants in the current experiment, analyses were conducted to investigate a possible discrepancy in male and female performance. No gender effects were uncovered.

Materials

The same stimuli and novel toy labels were used as those in Experiment 1 and 2. As was the case in Experiment 2, the sessions were recorded using two video cameras and a Hi-8 videocassette recorder.

Design and Procedure

Infants were exposed to the same design and procedure to that used in Experiment 1. However, prior to commencing the task, infants witnessed a contingent interaction between the robot and experimenter. Upon entering the testing room, infants were seated in an infant chair at the testing table. The experimenter was seated directly across the table from the child, with the robot in a high chair to the experimenter's left. The experimenter and robot engaged in a 60 second scripted conversation. More specifically, they greeted one another, played a copycat game, and said farewell according to a predetermined script. Specifically, the robot's verbal responses and movements were programmed to occur less than one second following the experimenter's to ensure that the interaction was contingent. The sequence was initiated by the experimenter who simply clicked a start button on the laptop computer controlling the robot, at the beginning of the interaction. At the end of the interaction, the experimenter proceeded with the word-learning task. As outlined in both previous experiments, a novel toy was labeled a total of four times in both training conditions. Infants were subsequently tested for their comprehension of novel and familiar words, four times each, in alternating order.

Coding

The amount of time infants looked at the robot, the experimenter, and at their caregiver during the 60 second interaction was coded. Of particular importance was that infants were watching the interaction. Participants who spent more than 25% of the time (15 seconds) looking at places other than the robot and the experimenter during this time were excluded from analyses. As indicated earlier, only one infant was excluded on this basis. Infants' performance during training and testing was coded in the same manner as in Experiment 1 and 2. All variables of eight infants (25%) were coded independently by two experimenters, who were in 99% agreement.

Results and Discussion

Looks During Training

Upon analysis, infants in the current task demonstrated the same interest in the speaker during the labeling trials as those in Experiment 1 and Experiment 2. More specifically, infants were found to orient to the robot at equally high levels in both conditions. Out of four trials, infants looked to the robot a mean of 3.57 (SD = 0.63) trials during the coordinated condition and a mean of 3.54 (SD = 0.74) trials in the discrepant condition, $t(27) = -0.19$), $p > .05$. Infants' looking behavior during training is presented in Table 3.

To ensure that infants were engaging in the same gaze-following behavior during training as in both previous experiments, their tendency to look to their own toy and to the robot's toy following a look to the robot was compared across conditions. Infants' mean looks to their own toy was no different in the coordinated condition compared to the discrepant condition, $t(27) = 1.09$, $p > .05$. This finding contrasts with the

Table 3

Mean Number of Looks to the Robot, Infants' Toy, and Robot's Toy During Training in Experiment 3

	Condition	
	Coordinated	Discrepant
Looks to robot	3.57 (0.63)[a]	3.54 (0.74)
Looks to infant's own toy	0.93 (0.98)	1.21 (1.00)
Looks to robot's toy	0.50 (0.69)	1.04 (0.92)

[a] Standard deviation in parentheses

performance of infants in Experiment 1, who looked to their own toy at significantly greater rates in the coordinated condition compared to the discrepant condition. Nonetheless, a comparison of the mean number of looks to the robot's toy yielded results consistent with our expectations and with both previous experiments. That is, following a look to the experimenter, infants looked to the robot's toy significantly more often in the discrepant condition as compared to the coordinated condition, $t(27) = 2.95, p < .05$. Consistent with the previous experiments, this finding suggests that at 18 months of age, infants appeared to shift their gaze as a function of the robot's gaze.

Comprehension Results

Familiar labels. Not surprisingly, infants performed at high levels on familiar label testing trials, and equally in both conditions. That is, infants selected the correct familiar item 78.27% ($SD = 27.06$) of the time in the coordinated condition and 66.07% ($SD = 34.17$) of the time in the discrepant condition. In both cases, these success rates were significantly greater than would be predicted by chance alone (50%) (Coordinated, $t(27) = 5.53, p < .05$; Discrepant, $t(27) = 2.49, p < .05$).

Novel labels. Of great interest was whether the addition of a contingent interaction to the word-learning task would enhance 18-month-old infants' ability to learn a new word from a nonhuman speaker. Should witnessing the robot and human experimenter interact contingently with one another lead to increase infants' perception of the robot as having communicative intentions, we would expect infants to select the correct novel toy during the testing phase. That is, we would expect infants to perform in a similar manner to those in Experiment 2 who viewed a human speaker label the novel toys. In contrast, if such an interaction were insufficient for 18-month-olds to perceive the robot as having the intent to label the novel object, infants would not be expected to select the correct novel toy. In this case, their performance would mirror that of the infants in Experiment 1. Like the infants in Experiment 1, infants in the current study performed quite poorly on novel label comprehension trials. More specifically, infants selected the robot's toy at equally low rates in both the discrepant condition (M = 49.41%, SD = 26.54) and coordinated condition (M = 46.43%, SD = 25.60), $t(27) = 0.44$, $p > .05$ (see Figure 7). In other words, infants successfully selected the correct novel item only 49.41% and 46.43% of the time in the discrepant and coordinated conditions, respectively. These success rates did not exceed chance expectations (50%) in either case (Coordinated, $t(27) = 0.74$, $p > .05$; Discrepant, $t(27) = -0.12$, $p > .05$). Thus, at 18 months of age, infants did not show evidence of word learning from a nonhuman speaker, even after witnessing this agent engage contingently with a human being. Consistent with infants in Experiment 1, those in the current experiment followed the robot's gaze to the novel object that it was labeling; however, they failed to select the appropriate toy during comprehension testing. These results suggest that infants did not use the robots' gaze to make the association between the novel word and its referent. The presence of contingency, along with self-propulsion and animate morphological features (e.g., eyes), does not appear to be sufficient to attribute communicative intent to a nonhuman agent.

MacArthur Communicative Development Inventory

To determine whether differences existed in infants' productive vocabularies between the current and previous experiments, we compared the vocabulary scores of the three groups. Specifically, the vocabulary size of infants in the current experiment did not differ (mean number of words = 109.85, SD = 108.42) from those in Experiment 1 (mean number of words = 78.05, *SD* = 85.41), $t(37) = -1.01$, $p > .05$. More importantly, the mean vocabulary size of infants in the current study and those in Experiment 2 (mean number of words =169.37, *SD* = 168.22) also did not differ significantly from one another, $t(37) = 1.32$, $p > .05$. These findings indicate that differences in performance on the word-learning task between the three groups can not be accounted for by differences in language abilities.

Gaze Following

The looking behavior of infants in Experiment 3 was very similar to the infants who participated in Experiment 1. That is, they shifted their gaze to orient toward the object at which the robot was gazing, however, their performance was not as robust as infants in Experiment 2 who were exposed to a human speaker. In particular, infants looked to the robot's toy equally often during the discrepant condition in Experiment 3 (Mean number of trials = 1.04, *SD* = 0.92) and Experiment 1 (Mean number of trials =1.50, *SD* = 1.45), $t(52) = 1.42$, $p > .05$. Likewise, the mean number of trials that infants looked to their own toy after orienting to the robot in the coordinated condition was not significantly different across the two experiments (Experiment 3, $M = 0.93$, $SD = 0.98$, Experiment 1, $M = 1.23$, $SD = 1.08$), $t(52) = 1.22$, $p > .05$. When the looking behavior of infants who viewed a contingently interacting robot label a new object was compared to those who watched a human speaker label a novel object, significant differences were obtained. Infants who observed the contingent robot looked to the robot's toy during the discrepant condition on fewer trials ($M = 1.04$, $SD = 0.92$) than did infants who observed the human speaker ($M = 2.40$, $SD = 1.12$), $t(51) = 4.78$, $p < .05$. Similarly, infants who observed the contingent robot looked at their own toy during the coordinated condition, on fewer trials ($M = 0.93$, $SD = 0.98$) than did infants who observed the human speaker ($M = 1.68$, $SD = 1.22$), $t(51) = 2.49$, $p < .05$. Overall, infants shifted their gaze as a function of the robot's gaze direction less in the case of a contingent robot speaker than when the speaker was human. Nevertheless, infants tracked the speaker's gaze in all three experiments.

Analyses were conducted to further clarify this pattern of results. When infants' looking behavior was combined across conditions (a total of 8 trials), the total number of trials that infants in Experiment 3 looked to the experimenter did not differ significantly from Experiment 1 (Experiment 3, $M = 3.36$, $SD = 2.02$; Experiment 1, $M = 3.81$, $SD = 2.26$; $t(52) = 0.77$, $p > .05$) or Experiment 2 (Experiment 2, $M = 2.88$, $SD = 1.85$; $t(51) = -0.89$, $p > .05$). However, differences were uncovered between the groups in terms of infants' tendency to look at a location other than the robot, experimenter, or novel toys following the utterance of the label. Infants who viewed a contingent robot (Experiment 3) were found to look toward their caregiver significantly more often during labeling (Mean number of trials = 2.61, $SD = 1.50$) than infants exposed to a human speaker (Experiment 2) (Mean number of trials = 1.44, $SD = 1.26$), $t(51) = -3.05$, $p < .05$. This finding is consistent with the pattern of results for Experiment 1, where infants who were exposed to a nonhuman speaker (Experiment 1) also looked at their caregiver more often than infants who were exposed to the human speaker (Experiment 2). A comparison of the extent to which infants looked at their caregivers in both robot tasks revealed no difference. More precisely, infants in Experiment 3 spent an equal amount of time looking away from the testing table and referencing their caregiver as infants in Experiment 1 (Mean number of trials = 2.73, SD = 1.66), $t(52) = 0.29$, $p > .05$. Taken together, these findings suggest that when confronted with a nonhuman agent, contingent or not, infants appear to require additional information as to how its behavior should be interpreted. As such, they seem to look away from the robot and the novel toys to their caregiver in search for guidance. Despite their limited word learning experience, they might already recognize that a nonhuman agent is not a conventional speaker as they have never experienced such agent talking (e.g., Diesendruck & Markson, 2001; Graham, Stock, & Henderson, 2006).

In sum, like those who participated in Experiment 1, infants involved in Experiment 3 were unsuccessful in the word-learning task. Despite witnessing the robot and experimenter engage in a contingent interaction prior to the testing procedure, infants still did not appear to consider the robot as having the intent to label a novel object. While they oriented to the appropriate novel object by following the robot's gaze, they did not show evidence of associating the new word and its referent. It appears then, that while contingent interaction may facilitate infants' attribution of goals and intentions to a nonhuman agent, at large, it does not specifically enhance infants' attribution of communicative intent to a non-human agent.

General Discussion

The purpose of the current study was twofold: firstly, to examine whether infants would follow the gaze of a nonhuman agent while labeling a novel object, and secondly, to determine whether in doing so they are able to properly link a novel word with its referent. Based on previous findings that 12-month-old infants consistently follow the gaze of an ambiguous object that possesses facial features or is capable of contingent interactions (Johnson et al., 1998), we expected that infants would demonstrate gaze-following behavior in the presence of a humanoid, self-propelled robot. However, we predicted that by the age of 18 months, this attentional orienting would not be sufficient for infants to attribute referential intent to the speaker, and thereby they would fail to map words onto the correct referent. The present set of three experiments produced two main findings. First, the results of Experiment 1 replicate and extend previous work by demonstrating that even infants as old as 18 months follow the gaze of a self-propelled inanimate object that possesses human-like features, even in the absence of contingent behavior. Secondly, and more importantly, the present findings show that although infants' attention can be directed to the appropriate object by the robot's gaze direction, there was no evidence that infants associated the unfamiliar label with the corresponding object. That is, when tested for their comprehension of novel words, they did not select the appropriate toy at above chance levels in either the discrepant or coordinated gaze conditions. This was the case, even when labels were produced by a contingently interacting robot in Experiment 3. It appears that the 18-month-olds in both robot conditions behaved like the 12-month-old infants in Baldwin's (1993) original experiment, who also monitored the speaker's gaze successfully but did not use this cue to establish the correct word referent, even in the coordinated condition. A strikingly different pattern of results emerged in Experiment 2, when infants completed the same word training procedure with a human speaker. In accord with previous studies, when the human speaker produced the label, infants followed her gaze and oriented toward the target novel toy. In contrast to Experiments 1 and 3, and consistent with Baldwin's original (1993) study with a human speaker, infants in Experiment 2 learned the new words in both the coordinated and discrepant gaze conditions, as demonstrated by their tendency to correctly select the novel items more often than would be predicted by chance during comprehension testing. As expected, infants in all experiments demonstrated an understanding of the task requirements by selecting the correct familiar item at above chance levels.

We believe that the dissociation between gaze following behavior and the attribution of referential intentions is an important one due to the potential clinical implications of this distinction. Interestingly, the same type of distinction has been observed in autistic populations. A key deficit found in autistic children is their lessened ability to formulate a theory of mind (ToM), the understanding that others have mental states different from one's own. Baron-Cohen, Baldwin, and Crowson (1997) applied the methodology of Baldwin's (1993) original word learning task, to a study involving 9-year-old children with autism. Unlike normally developing children who engaged in the word learning task, Baron-Cohen and colleagues (1997) reported that autistic children were unable to establish correct word mappings in either the coordinated or discrepant condition, which the authors attributed to the autistic children's failure to *use* the speaker's eye-gaze. Instead, they associated new labels with the object that was the focus of their own attention.

No doubt, there are alternative interpretations for the absence of word mapping in the case of a nonhuman speaker. One interpretation is that infants may have learned the association between the word and the object but were unable to generalize this association from the robot to the experimenter. This could be due to the fact that infants failed to treat the robot as a reliable speaker. Recent research has shown that when presented with two informants, one who provides consistently accurate names for familiar objects and one who provides consistently inaccurate names, preschoolers reliably identify the unreliable informant and learn novel words from the reliable informant (Clement, Koenig, & Harris, 2004; Koenig & Harris, 2005; Sabbagh & Baldwin, 2001). Although similar word learning research has not been conducted with toddlers, a recent study has shown that infants as young as 14 months are less likely to follow the gaze of a person behind a barrier when her gaze was unreliable in another context (Chow et al., in press). Thus, if infants viewed the robot as an unreliable speaker, it remains possible that prior exposure to the robot correctly labeling familiar objects could have changed infants' perspective on this agent. Another interpretation concerns the perception of the robot as an unconventional speaker, that is, that the labels he uses are unique to him and are not generalizable to human speakers. Preschoolers and even toddlers presume that individuals share the knowledge of the meaning of novel labels, even in the absence of explicit evidence that this is the case (Diesendruck & Markson, 2001; Graham et al., 2006). This interpretation would be supported if, in future studies, infants learn the novel words when the robot is both the speaker and the tester. Because our robot did not have mobile arms, word comprehension trials were conducted by a human tester, a factor that we tried to control for by having the same procedure in the person condition.

As mentioned before, there are two theoretical approaches to the origins of infants' concept of intentional agent. According to some researchers, infants' attributions of intentional behavior are activated whenever infants recognize an object as a psychological agent, based on an evolutionary designed system which is sensitive to certain cues such as self-propulsion, contingent reactivity or equifinal variation of the action (Baron-Cohen, 1995; Gergely & Csibra, 2003; Johnson, 2000; Leslie, 1995). Other researchers reject this cue-based perspective and propose that infants' understanding of intentional actions is restricted only to human actions (Meltzoff, 1995; Meltzoff & Brooks, 2001; Woodward et al., 2001). Although there is some evidence that infants do construe nonhuman agents as intentional beings, to date much of this research has been limited to infants aged 6 to 12 months and to goal detection and gaze-following abilities (Johnson et al., 2001; Johnson et al., 1998; Luo & Baillargeon, 2005). Tracing developmental changes in the breadth of infants' concept of agent beyond this early age range and on a task that requires infants to use the agent's gaze to learn was the main goal of the present study. The present findings extend prior research by showing that, like younger infants, 18-month-old infants follow the gaze of both human and nonhuman agents. However, children at this age use the speaker's direction of gaze as a strategy to correctly map a novel label only in the case of a human speaker. The present results suggest that by 18 months, the scope of infants' attributions of intent has narrowed; a finding that is in accord with previous research showing that infants do not attribute goals to nonhuman, unfamiliar objects (Meltzoff, 1995). The fact that the nonhuman agent used in the present experiments had many obvious physical and behavioral similarities to humans (e.g., body, head, facial features, voice, contingency) provides a more stringent test of infants' interpretation of gaze than previous studies. Nevertheless, because the present word mapping task could only be administered to 18 month-olds, the developmental period during which there are changes in infants' concept of intentional agent remains to be documented with other tasks. The present experiments, together with other recent work examining precursors to theory of mind skills in infancy, suggest that the period between 12 and 18 months represents a milestone in infants' understanding of these concepts that also corresponds with significant changes in how infants interpret the actions of human and nonhuman agents (Bellagamba & Tomasello, 1999; Olineck & Poulin-Dubois, 2005; Poulin-Dubois, 1999; Repacholi & Gopnik, 1997).

Chapter 5. General Discussion

The current dissertation sought to gain an understanding of infants' *implicit* understanding of mental states. Specifically, this thesis focused on infants' appreciation of the epistemic nature of eye gaze and on their concept of mentalistic agent during the second year of life.

The first paper examined infants' understanding of the relationship between visual perception and knowledge. Two methodological paradigms were used in an effort to understand whether infants appreciate that eye gaze can be used to make inferences about another person's knowledge. When infants were presented with an interactive search task, 24-month-olds demonstrated an understanding that people's eyes need to be unobstructed in order for them to be connected to the external world; a necessary prerequisite for understanding that seeing affords a person with knowledge. However, when infants were presented with another interactive task designed to ascertain whether they are capable of inferring a person's knowledge on the basis of her visual access or lack thereof, infants did not exhibit a clear understanding of the causal link between visual perception and knowledge. This issue was explored further by using a preferential looking paradigm designed to capitalize on infants' tendency to respond to a violation of their expectancies. Using this procedure, 18-month-olds demonstrated that they expected a person who could see to correctly search for a hidden object, while they expected a person who could not see to search incorrectly. Thus, this finding offers an important contribution to the literature on infants' early cognitive development, as it provides preliminary evidence that infants took the person's visual experience into account and predicted different behavior as a function of the person's prior experience. This finding can be interpreted in two ways: a rich interpretation would propose that infants inferred the person's knowledge on the basis of her visual experience, while a leaner interpretation would suggest that infants may have formed a simple association between the person's behavior and the object.

In the second paper, infants' understanding of the epistemic nature of eye gaze was studied further by contrasting infants' attributions of knowledge or ignorance when looking behavior was displayed by a person or by a humanoid robot that displayed animate features and motion characteristics. The preferential looking paradigm was used to assess infants' expectations regarding the relationship between visual perception and knowledge in this regard. Consistent with findings from the first paper, infants appeared to appreciate that when a person sees an event, she has unique knowledge about the event, which ultimately impacts her behavior. Thus, these findings lend support for the notion that infants have an implicit, rudimentary understanding that visual perception affords a person with unique knowledge. However, infants did not demonstrate this expectation when looking behavior was exhibited by a humanoid robot. Moreover, infants appeared to be puzzled and looked longer when the robot's eyes were blindfolded compared to when the robot's eyes were unobstructed, while infants in the person group did not show this pattern. Overall, infants clearly treated the person and the robot's gaze differently. These findings provide insight into infants' concept of mentalistic agent and suggest that by 18 months of age, infants do not broadly attribute mental states to inanimate objects, despite the presence of several animate features and motion characteristics. Moreover, a differential response to the robot and person lends support to the experience-based view regarding infants' attributions of mental states. If infants were simply responding based on computation of action-object associations, as proposed by the cue-based view, one would expect to see the same pattern of results, regardless of the identity of the agent.

The third paper explored infants' understanding of the epistemic nature of eye gaze within the context of a word learning task. Of particular interest was whether infants would use eye gaze to attribute referential intent to a human and a non-human speaker in a word learning context. Using an established word learning procedure, three experiments were conducted where 18-month-olds were exposed to either a human or non-human speaker who uttered novel labels for unfamiliar objects under two different eye gaze conditions. The results replicate and extend previous work by demonstrating that 18-month-old infants follow the gaze of a self-propelled inanimate object that possesses human-like features, even in the absence of contingent behavior. However, while infants' attention was directed to the appropriate object by the robot's gaze direction, infants failed to associate the label with the corresponding object. The same pattern was observed when labels were produced by a contingently interacting robot. Thus, while infants followed the eye gaze of the non-human speaker, they did not use the robot speaker's eye gaze cues to determine the correct referent of novel words. Moreover, addition of contingent interaction did not facilitate infants' attribution of referential intent to the robot speaker. These findings contrast directly with those obtained when infants completed the same procedure with a human speaker. Consistent with previous research, when the human speaker produced the label, infants followed her gaze and oriented toward the target novel toy, and also learned the labels for the novel objects in both eye gaze conditions. These results contribute to the literature by demonstrating that although infants' attention was directed to a particular object by the gaze direction of a humanoid robot, infants did not attribute referential intent to the non-human speaker in the same manner as they did when the speaker was human. Evidence for such a dissociation between gaze following behavior and the attribution of referential intentions is a unique finding that has theoretical implications for understanding infants' concept of mentalistic agents. Furthermore, these results provide additional evidence for the notion that by 18 months, the scope of infants' attributions of intent has narrowed (Meltzoff, 1995) relative to that demonstrated by younger infants.

Contributions

This dissertation took a two-pronged approach to examine whether infants appreciate the mentalistic nature of eye gaze. On the one hand, this thesis examined whether infants have some grasp that eye gaze can be used to make inferences about another person's knowledge. On the other hand, infants' understanding of the epistemic nature of eye gaze was investigated by testing whether infants' inferences based on eye gaze extend to any agent that displays looking behavior.

To date, it has been widely accepted that children do not explicitly understand the relationship between visual perception and mental states until age four (e.g., Pillow, 1989; Povinelli & de Blois, 1992; Pratt & Bryant, 1990; Wimmer et al., 1988; Woolley & Wellman, 1993). However, whether children possess an *implicit* understanding of the mentalistic nature of eye gaze during the second year of life remains an issue of debate. Findings from the present series of experiments suggest that children likely do possess an implicit, basic understanding of the relationship between visual perception and knowledge well before four years of age. In particular, 18-month-olds demonstrated a level of understanding that appears to be a step beyond understanding the connection between the looker and the object of her gaze (i.e., level two gaze understanding), but is nonetheless insufficient for a full-fledged understanding of the mental significance of gaze (i.e., level three gaze understanding). Specifically, 18-month-olds used information about a person's visual access to predict her future behavior. As such, there appears to be evidence for subtle changes in infants' understanding of the relationship between visual perception and knowledge, which follow a level two understanding of eye gaze and may serve as a precursor to the sophisticated level of understanding of eye gaze that is exhibited by preschoolers and adults. At this new step, infants appear to have some preliminary understanding of the epistemic aspects of seeing.

While the present results suggest that 18-month-olds likely possess an implicit, basic understanding of the relationship between visual perception and knowledge, it is plausible that a leaner explanation may account for these results. For instance, it may be that infants simply predicted that a person will act toward an object after orienting her gaze and head toward it, without any appreciation of the epistemic nature of eye gaze (Perner & Ruffman, 2005). It is possible that infants responded based on this type of behavioral regularity without having any conception that the mind mediates between a person's gaze and her behavior. A similar argument has been made about data suggesting false-belief understanding in infancy (e.g., Onishi & Baillargeon, 2005; Perner & Ruffman, 2005). This explanation seems unlikely however, given the accumulation of research which shows that infants understand that looking behaviour results in 'seeing' by 12 to 14 months of age. For example, infants are more likely to follow gaze when a person's eyes are open or unobstructed than when they are closed, and will move to follow an adult's gaze to a location that is outside of their view (Brooks & Meltzoff, 2002; Moll & Tomasello, 2004). Moreover, recent research showing that 14-month-olds' gaze following differs as a function of their experience with the looker (i.e., reliable vs. unreliable), provides further evidence that infants appreciate the referential and experiential nature of another person's gaze (Chow et al., in press). Lastly, if infants' responses were best accounted for by a rule-based explanation such as that described above, one would expect infants to have performed similarly in the person and robot conditions, which was not the case. Thus, it appears unlikely that infants' responses are simply based on a rule-based phenomenon and the present findings are most consistent with the hypothesis that infants have a developing understanding of the experience of seeing by 18 months of age.

Recent studies focusing on other areas of early mental state understanding also lend support to this notion. For instance, by 14 months, infants are capable of representing another person's visual perspective. Using a looking time paradigm, Sodian and colleagues (Sodian et al., 2007) examined whether 12- and 14-month-olds would take into account the reasons a person may have for changing her goal-directed action (i.e., she could no longer see the goal object). Their results revealed that only 14-month-olds were able to 'rationalize' a person's action by taking her visual perspective into account. These findings indicate that 14-month-olds are capable of level one perspective taking; they understand that another person may see something that he or she does not see. In addition, these findings suggest that infants' grasp of seeing is more sophisticated than merely understanding the referential nature of eye gaze (level two understanding), as infants were required to interpret a person's goal-directed action as rational or irrational based on the person's access to visual information. In this way, 14-month-old infants seem to appreciate that looking affords a person with information about the world and took this into account when interpreting the person's behavior. The present results are also consistent with recent evidence for a developmental progression in infants' understanding of the seeing-knowing relation, which emerges between 14 and 18 months of age (Poulin-Dubois, Sodian et al., 2007). The data from Poulin-Dubois and colleagues are consistent with the present results, and provide evidence that by 18 months, infants appreciate that people's eye gaze can be used to predict their future behavior. Because a person's epistemic state can be inferred from her access to information, the ability to correctly represent what others can and cannot see is necessary for the successful attribution of knowledge or beliefs. Indeed, because infants are capable of level one perspective taking at 14 months of age, it is not surprising that four months later, they would have the ability to use this appreciation to help them understand the world around them in a slightly more sophisticated manner. In this sense, level one perspective taking and the subsequent appreciation of the relationship between visual access and knowledge can be viewed as important precursors to theory of mind. Overall, the present findings provide corroborating evidence that infants possess an implicit understanding of the mentalistic nature of seeing much earlier than researchers originally expected.

The notion that infants possess an implicit understanding of the mentalistic nature of seeing earlier than expected is consistent with recent findings which suggest that young infants also appear to be capable of representing another person's false beliefs much earlier than originally believed. In a groundbreaking paper, Onishi and Baillargeon (2005) reported that 15-month-old infants may attribute false beliefs to others. In this experiment, a violation of expectancy paradigm was used to present infants with a modified version of the classic false belief task. Strikingly, infants were found to look significantly longer when the person's behavior was incongruent compared to when it was congruent with a false belief. Thus, the authors interpreted these findings as evidence that infants predicted the person's behavior by taking her belief state into account. While the interpretation of these findings has been challenged (e.g., Perner & Ruffman, 2005), other research that controls for the limitations inherent in Onishi and Baillargeon's work also suggests that young infants are capable of representing another person's beliefs. In one such study, the violation of expectancy paradigm was used to examine whether 13-month-old infants' expectations about an agent's future actions would take into account the agent's previous exposure to relevant information about an object's location (Surian, Caldi, & Sperber, 2007). Infants' looking times revealed that they attributed beliefs to the agent and expected that the agent's behavior would be guided by true beliefs. In another experiment, eye-tracking technology was used to measure infants' anticipation of a person's actions (Southgate, Senju, & Csibra, 2007). These results demonstrated that 25-month-olds correctly anticipated a person's actions when these actions could only be predicted by attributing a false belief to the person. Thus, infants are clearly sensitive to the belief state of other individuals and they appear to take this information into account when observing a person's actions. While this knowledge is evidently not as sophisticated as a preschooler's would be, infants clearly demonstrate a basic appreciation of mental state reasoning much earlier than expected.

Research documenting young children's sensitivity to early forms of mental state understanding is surprising given their consistent failure on standard tasks of mental reasoning abilities (see Wellman, Cross, & Watson, 2001). However, use of differing methodologies may provide an explanation for this discrepancy. For instance, several disadvantages of the standard false-belief task have recently become apparent and suggest that children's understanding of mental states may not be most accurately assessed by this task. The most inherent problem with the standard false-belief task is that it requires abilities other than understanding mental states, such as language (Bloom & German, 2000). In addition, children below the age of four may have trouble with the standard false-belief task due to a reality-bias, which occurs when the child's own knowledge about a situation interferes with her ability to respond accurately. It has been proposed that verbal tasks may be more likely to elicit the reality-bias (Southgate et al., 2007). Moreover, as children are well-known to have difficulty with tasks that require inhibitory control, this factor may confound their responses even further. Thus, one explanation for the discrepancy in these results is that children's difficulty on false-belief tasks is due to limitations in their performance on these tasks rather than limitations in their ability (Southgate et al., 2007). Given this possibility, it is critical that a variety of experimental methods be used to examine young children's mental state understanding. Therefore, a strength of the present thesis is that it involved the use of a variety of non-verbal methods to assess infants' knowledge. Looking time in particular is known to provide a rich source of information, and it is well-documented that looking time studies reveal sensitivity to variables at earlier ages than more explicit tasks do, although the reasons for this have been debated (Haith, 1998). Other dependent measures, such as pointing or searching behaviors have also revealed infants' appreciation of variables at an earlier age than tasks that require a verbal response.

However, even when non-verbal tasks are used, there have been discrepancies in findings. Recently, it has been proposed that discrepancies between findings from tasks that are based on looking time (i.e., expectancy-violation tasks) and those that require an explicit response (i.e., pointing or searching) may be due to different abilities underlying these different types of tasks. Specifically, recognition of incongruent events may support a looking response, while success on more explicit tasks may require infants to make a prediction, which is inherently more complex (Southgate et al., 2007). Thus, it seems reasonable to predict that evidence for infants' understanding of mental states would be documented at younger ages when tasks employ looking time measures based on a violation of expectancy paradigm, compared to tasks that require infants to make a response such as pointing or searching, and lastly, tasks that require a verbal response. Further research is clearly needed to systematically compare infants' performance on different types of tasks that are presumed to be measuring the same variable. Nevertheless, in the past decade, there has been a revolution in developmental psychology as advances in experimental methods have enabled researchers to gain access to young children's thoughts and expectations.

In a related vein, the question of whether infants appreciate that mental states are uniquely human has been an issue of considerable debate. This issue was examined directly by testing whether infants' inferences based on eye gaze extend to any agent that displays looking behavior. Several interesting findings emerged that suggest that 18-month-olds treated a human agent and a humanoid robot quite differently. First, in the second paper, infants in the robot group looked longer during test trials when the robot was blindfolded compared to when the robot's eyes were unobstructed, while infants in the person group did not show this pattern. Because this pattern was not observed during the information phase, it seems that infants were surprised to see the blindfolded robot subsequently pointing. At the very least, this finding suggests that infants clearly treated the function of the eyes for differently the person and the robot.

Furthermore, when the results from the second and third paper are considered together, there is strong support for the notion that 18-month-old infants conceptualized the robot as a different type of agent than the human. In both papers, infants treated the robot's gaze differently from that exhibited by the human agent. In the second paper, infants appeared to expect a different type of relationship between the agent and the focus of its gaze, as a function of the identity of the agent. Specifically, infants appeared to appreciate that when a person sees an event, she has unique knowledge about the event, which ultimately impacts her behavior, while they did not demonstrate this expectation when the agent was a humanoid robot. In the third paper, while infants followed eye gaze exhibited by both the person and the robot speaker, infants in the robot condition did not associate the label with the corresponding object while infants in the person condition performed like infants in past studies and used the speaker's direction of eye gaze to associate the label with the correct object. Therefore, across both papers, when 18-month-olds observed a human and non-human agent exhibit the same looking behavior, they did not make attributions of knowledge or referential intent equally to both types of agent.

These findings are quite impressive given that the humanoid robot used in these experiments possessed distinctive facial features and behavioral characteristics that are similar to humans and that have been proposed to play a key role in infants' ability to differentiate different types of agents (e.g., large movable eyes, mouth, head, voice, self-propelled motion, contingent interaction). In light of these characteristics, the humanoid robot provided a stringent test of infants' interpretation of gaze. Nevertheless, despite the presence of salient animate perceptual features and behavioral cues, infants did not treat the human and the robot similarly. In contrast with the results obtained by Johnson and colleagues (2001), this was the case even when the role of contingency was directly examined in the third paper. As such, these findings provide insight into the role that perceptual features and motion characteristics play in 18-month-olds' concept of mentalistic agent.

The present dissertation also makes a unique contribution to the literature by providing evidence for a dissociation between gaze following behavior and the attribution of referential intent. Recall that in the third paper, 18-month-olds clearly monitored the robot speaker's gaze correctly, but did not use this cue to establish the correct word referent. This performance is similar to the 12-month-olds in Baldwin's (1993) original experiment, who also monitored the speaker's gaze successfully but did not use this cue to associate the label with the correct object, even in the coordinated gaze condition. Thus, while infants' attention was directed to the appropriate object by the robot's gaze direction, infants failed to associate the label with the corresponding object. These findings are consistent with past research demonstrating that 12-month-olds follow the gaze of an ambiguous object that possesses facial features or is capable of contingent interactions (Johnson et al., 1998). However, it appears that by the age of 18 months, this attentional orienting is not sufficient for infants to attribute referential intent to the speaker. Clinically, it is also interesting to note that a similar distinction has been observed in autistic populations. When the same word learning task was used with 9 year old children with autism and typically developing children (Baron Cohen et al., 1997), children with autism were unable to use the speaker's eye gaze to establish correct word mappings. Instead, children with autism made errors because they associated the labels with the object that was the focus of their own attention, and did not take the speaker's focus of attention into account. Based on the apparent dissociation between gaze following and attributions of referential intent, it appears that gaze following behavior may reflect an attentional orienting response that does not necessarily involve an attribution of epistemic states.

The present findings extend prior research by showing that, like younger infants, 18-month-old infants follow the gaze of both human and nonhuman agents. However, the results from the second and third papers suggest that infants nevertheless conceptualized the robot and the human differently. Together, these findings add to the literature on infants' concept of mentalistic agent. As mentioned earlier, there are two theoretical approaches to the origins of infants' concept of intentional agent. On the one hand, proponents of the *cue-based view* maintain that infants' attributions of intentional behavior are activated whenever infants recognize an object as a psychological agent based on an evolutionary designed system which is sensitive to certain behavioral cues, regardless of the identity of the agent (Baron-Cohen, 1995; Csibra et al., 1999; Gergely et al., 1995; Johnson, 2000; Leslie, 1995). As such, this view proposes that infants attribute goal directed behavior to a wide range of entities, including unfamiliar inanimate agents, and do not interpret human and non-human actions differently (i.e., infants' concept of mental agent is broad and abstract). On the other hand, proponents of the *experience-*

based view maintain that infants restrict attributions of intent to human action and do not attribute mental states broadly. Moreover, it is proposed that infants acquire this understanding gradually through experience with human agents, via their own actions and interactions with social partners (Meltzoff, 1995; Tomasello, 1999; Woodward et al., 2001). Although there is some evidence that infants do construe non-human agents as intentional beings, much of this research has been limited to infants aged 6 to 12 months and has been focused on goal detection and gaze-following abilities (Johnson et al., 2001; Johnson et al., 1998; Luo & Baillargeon, 2005). When these results are considered in light of the apparent dissociation between gaze following and attributions of intent, it is plausible that infants' early gaze following in these studies may reflect their response to the attentional spotlight that is provided by eye gaze, and may not necessarily speak to their concept of mentalistic agent per se. In contrast, based on infants' different responses to looking behavior exhibited by the person and the robot, the present findings are most consistent with the experience-based view. At 18 months, infants differentially attributed knowledge and referential intent to a human and a non-human agent. That is, by this age, infants did not attribute mental states broadly, a finding that is in accord with previous research showing that similar aged infants do not attribute goals to nonhuman, unfamiliar objects (Meltzoff, 1995).

Overall, it appears that there may be different levels of infants' understanding of intentional agents. At a preliminary level, infants may detect intentional agents without necessarily understanding or attributing mental states to those agents. The presence of eyes and behavioral motion cues may serve as important cues at this level. However, at this stage, it appears that gaze-following behavior does not reflect any appreciation of the mentalistic nature of eye gaze. By the end of the second year of life, infants' concept of mentalistic agent appears to be more refined. At this level, infants begin to attribute epistemic states to agents differentially. In this process, eye gaze cues may serve to provide important information about a person's focus of attention, which can be used to infer intent and predict subsequent behavior, but eye gaze cues alone are not sufficient.

Future Directions

The study of infants' early responses to human behaviors offers valuable insights into the human mindpsyche, the nature of children's development, and the unique capabilities of the human species. Nonetheless, there are important gaps in the literature and debate continues regarding how to interpret infants' behaviors. There are several avenues of prospective research that would offer further clarification of these issues.

Future research that explores the precise nature of infants' appreciation of the connection between visual perception and other's epistemic states would be valuable. For instance, one unresolved issue is whether infants appreciate that people's mental states are influenced by the quality of their perceptual connectedness to objects in the world, as demonstrated by adults and older children (Montgomery et al., 1998). Recent research examining 14- and 18-month-olds' reenactment of intentional and accidental actions provides indirect evidence that by 18 months, infants are more likely to consider prolonged looking at and touching an object as markers of intentional action (Olineck & Poulin-Dubois, 2005). However, whether infants attribute mental states differently when looks are brief versus when they are prolonged remains to be determined. Another issue that warrants further systematic investigation is the developmental progression in infants' understanding of the relationship between visual perception and knowledge during the second year of life. While there is evidence for developmental changes between 14 and 18 months of age (e.g., Poulin-Dubois, Sodian et al., 2007), further research that systematically tracks the changes in infants' understanding of visual perception between 12 and 24 months, would bolster our understanding of infants' appreciation of visual perception. Moreover, examining the relationship between infants' understanding of visual perception and other theory of mind abilities, such as desire or intention, would potentially provide further support for the hypothesis that these abilities serve as early precursors to theory of mind.

Another potential avenue for future research involves clarification of infants' concept of mentalistic agent over time. For instance, controlled experiments that systematically compare whether infants of different ages make mental state attributions when agents display specific features or motion characteristics, would provide valuable information about how infants' concept of mental agent may change with age. Thus, prospective, longitudinal studies would enable the opportunity to look at emergent abilities as they occur, and would also allow for more in-depth examination of individual differences in the development of mental state understanding. Moreover, the relative importance of different cues and how they may be used differently by infants of different ages and in different contexts remains to be determined. It would be interesting to explore infants' attributions of mental states to human and non-human agents across a variety of mental states, such as knowledge/beliefs, desires and intentions. If infants perform similarly, and treat human and non-human agents differently across a range of different mental states, this would provide stronger evidence for the claim that infants do indeed appreciate that humans possess mentalistic capabilities, while non-humans do not.

Over time, it is critical that studies that examine these issues should employ a wide range of methodologies and dependent variables (i.e., habituation, preferential looking, and interactive procedures). Only when findings converge across methods and measures will we be able to make firm conclusions about the nature of young children's understanding of mental states and their concept of mentalistic agent. Recent evidence suggests that different measures may tap into different abilities, although this has yet to be empirically investigated. As mentioned previously, further research is needed to systematically compare infants' performance on different types of tasks that are presumed to be measuring the same variable. This issue has both theoretical and empirical implications, and holds exciting promise for clarifying the conclusions that can be made on the basis of young infants' responses in experimental tasks. Moreover, use of longitudinal procedures should not be overlooked as a valuable tool to evaluate children's developing understanding of mental states across time. Specifically, with regard to understanding the relationship between visual perception and knowledge, one would expect to find evidence for continuity in children's understanding in infancy, as measured by looking-time paradigms (e.g., Poulin-Dubois, Sodian et al., 2007), and their understanding at later ages, as measured by their explicit responses (e.g., Povinelli & de Blois, 1992; Wimmer et al., 1988). Evidence for continuity in children's performance from infancy to early childhood would also serve to validate the tasks and procedures used to assess mental state understanding in infancy.

Finally, an important direction for future research relates to the application of this work to atypical populations. Preliminary research suggests that there are differences in how typically developing children and those with autism use eye gaze cues (Baron-

Cohen, 1995; Baron Cohen et al., 1997), however the meaning of these differences is not yet fully understood. Further research should aim to gain a better understanding of the variability observed in both typically and atypically developing children's performance on early theory of mind tasks and the predictive power of these tasks for later abilities. In particular, developing tools that would aid in diagnosis and intervention would be invaluable for parents and health professionals.

In sum, the present series of experiments add to the literature on early naïve psychology by showing that infants' understanding of eye gaze becomes more sophisticated with increasing age. By 18 months, infants appear to appreciate that visual perception affords a person with unique knowledge. Specifically, at this age, infants understand that a person will behave differently when looking for a hidden object depending on whether the person was able or unable to see where the object was located. The present experiments also contribute to the existing literature on infants' concept of mentalistic agent by showing that 18-month-olds do not treat eye gaze cues similarly when they are exhibited by a person and a non-human agent. At this age infants appear to understand that eye gaze cues serve to provide important information about the focus of attention, but are insufficient for attribution of epistemic states, such as knowledge or referential intent. Thus, when considered with existing literature, the present experiments lend support to the notion that 18-month-old infants consider people as unique beings that are capable of possessing mental states, while they do not attribute the same qualities to a non-human agent. These findings are consistent with the hypothesis that young children possess some rudimentary appreciation of other's mental states earlier than previously proposed.

References

Akhtar, N., & Tomasello, M. (2000). The social nature of words and word learning. In G. R. & K. Hirsh-Pasek (Eds.), *Becoming a Word Learner: A Debate on Lexical Acquisition.* New York, NY: Oxford University Press.

Arita, A., Hiraki, K., Kanda, T., & Ishiguro, H. (2005). Can we talk to robots? Ten-month-old infants expected interactive humanoid robots to be talked to by persons. *Cognition, 95*, B49-B57.

Atkinson, D. (2000). Habit 2000 [Computer Software]. Austin, TX.

Baldwin, D. A. (1991). Infants' contribution to the achievement of joint reference. *Child Development, 62*, 875-890.

Baldwin, D. A. (1993). Infants' ability to consult the speaker for clues to word reference. *Journal of Child Language, 20*(2), 395-418.

Baldwin, D. A. (1995). Understanding the link between joint attention and language. In C. Moore & P. J. Dunham (Eds.), *Joint attention: Its origins and role in development* (pp. 131-158). Hillsdale, NJ: Lawrence Erlbaum.

Baldwin, D. A., & Moses, L. J. (1994). Early understanding of referential intent and attentional focus: Evidence from language and emotion. In C. Lewis & P. Mitchell (Eds.), *Children's Early Understanding of Mind* (pp. 133-156). Hillsdale, NJ: Lawrence Earlbaum.

Baron-Cohen, S. (1995). *Mindblindness: An essay on autism and theory of mind.* London, England: The MIT Press.

Baron Cohen, S., Baldwin, D. A., & Crowson, M. (1997). Do children with autism use the speaker's direction of gaze strategy to crack the code of language? *Child Development, 68*(1), 48-57.

Bellagamba, F., & Tomasello, M. (1999). Re-enacting intended acts: Comparing 12- and 18-month-olds. *Infant Behavior and Development, 22*, 277-282.

Bennett, P., & Poulin-Dubois, D. (1998). *Young children's understanding of attentional focus and seeing=knowing.* Paper presented at the International Conference on Infant Studies, Atlanta, GA.

Biro, S., & Leslie, A. M. (2007). Infants' perception of goal-directed actions: development through cue-based bootstrapping. *Developmental Science, 10*, 379-398.

Bloom, P. (2002). Mindreading, communication, and the learning of the names for things. *Mind and Language, 17*, 37-54.

Bloom, P., & German, T. P. (2000). Two reasons to abandon the false belief task as a test of theory of mind. *Cognition, 77*, B25-31.

Bretherton, I. (1991). Intentional communication and the development of mind. In D. Frye & C. Moore (Eds.), *Children's theories of mind, mental states and social understanding* (pp. 49-76). Hillsdale, NJ: Lawrence Erlbaum.

Brooks, R., & Meltzoff, A. N. (2002). The importance of eyes: How infants interpret adult looking behavior. *Developmental Psychology, 38*(6), 958-966.

Butler, S. C., Caron, A. J., & Brooks, R. (2000). Infant understanding of the referential nature of looking. *Journal of Cognition and Development, 1*(4), 359-377.

Butterworth, G., & Jarrett, N. (1991). What minds have in common is space: Spatial mechanisms serving joint visual attention in infancy. *British Journal of Developmental Psychology, 9*, 55-72.

Caron, A., Caron, R., Caldwell, R., & Weiss, S. (1973). Infant perception of the structural properties of the face. *Developmental Psychology, 9*, 385-399.

Caron, A., Caron, R., Roberts, J., & Brooks, R. (1997). Infant sensitivity to deviations in dynamic facial-vocal displays: The role of eye regard. *Developmental Psychology, 33*, 802-813.

Caron, A., Kiel, E. J., Dayton, M., & Butler, S. C. (2002). Comprehension of the referential intent of looking and pointing between 12 and 15 months. *Journal of Cognition and Development, 3*, 445-464.

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development, 63*(4, Serial No. 255).

Chow, V., Poulin-Dubois, D., & Lewis, J. (in press). To see or not to see: Infants prefer to follow the gaze of a reliable looker. *Developmental Science*.

Clement, F., Koenig, M., & Harris, P. (2004). The ontogenesis of trust. *Mind and Language, 19*, 360-379.

Clements, W. A., & Perner, J. (1994). Implicit understanding of belief. *Cognitive Development, 9*, 377-395.

Csibra, G., & Gergely, G. (1998). The teleoplogical origins of mentalistic action explanations: A developmental hypothesis. *Developmental Science, 1*, 255-259.

Csibra, G., Gergely, G., Bíró, S., Koós, O., & Brockbank, M. (1999). Goal attribution without agency cues: The perception of 'pure reason' in infancy. *Cognition, 72*, 237-267.

Csibra, G., & Volein, A. (in press). Infants can infer the presence of hidden objects from referential gaze information. *British Journal of Developmental Psychology.*

D'Entremont, B. (2000). A perceptual-attentional explanation of gaze following in 3- and 6-month-olds. *Developmental Science, 3*, 302-311.

D'Entremont, B., Hains, S. M. J., & Muir, D. (1997). A demonstration of gaze following in 3- to 6-month-olds. *Infant Behavior and Development, 20*, 569-572.

Diesendruck, G., & Markson, L. (2001). Children's avoidance of lexical overlap: A pragmatic account. *Developmental Psychology, 37*, 630-641.

Dunham, P., Dunham, F., & O'Keefe, C. (2000). Two-year-olds' sensitivity to a parent's knowledge state: Mind reading or contextual cues? *British Journal of Developmental Psychology, 18*, 519-532.

Dunham, P., Dunham, F., Tran, S., & Akhtar, N. (1991). The non-reciprocating robot Effects on verbal discourse, social play, and social referencing at two years of age. *Child Development, 62*, 1489-1502.

Dunphy-Lelii, S., & Wellman, H. M. (2004). Infants' understanding of occlusion of others' line-of-sight: Implications for an emerging theory of mind. *European Journal of Developmental Psychology, 1*, 49-66.

Flavell, J. H. (1992). Perspectives on perspective taking. In H. Beilin & P. Pufall (Eds.), *Piaget's theory: Prospects and possibilities* (pp. 107-139). Hillsdale, NJ: Erlbaum.

Flavell, J. H. (1999). Cognitive development: Children's knowledge about the mind. *Annual Review in Psychology, 50*, 21-45.

Flom, R., Lee, K., & Muir, D. (2007). *Gaze-following: Its developmental significance*. Mahwah, NJ: Lawrence Earlbaum.

Garnham, W. A., & Ruffman, T. (2001). Origin and truth: Young children's understanding of imaginary mental representations. *Developmental Science, 4*, 94-100.

Gergely, G., & Csibra, G. (2003). Teleological reasoning in infancy: The naive theory of rational action. *Trends in Cognitive Sciences, 7*, 287-292.

Gergely, G., Nádasdy, Z., Csibra, G., & Bíró, S. (1995). Taking the intentional stance at 12 months of age. *Cognition, 56*, 165-193.

Gopnik, A., Slaughter, V., & Meltzoff, A. N. (1994). Changing your views: How understanding visual perception can lead to a new theory of mind. In C. Lewis & P. Mitchell (Eds.), *Children's early understanding of mind.* UK: Lawrence Earlbaum.

Graham, S., Stock, H., & Henderson, A. (2006). Nineteen-month-olds' understanding of the conventionality of object labels versus desires. *Infancy, 9*, 341-350.

Haith, M. (1998). Who put the cog in infant cognition? Is rich interpretation too costly? *Infant Behavior and Development, 21*, 167-180.

Hare, B., Call, J., Bryan, A., & Tomasello, M. (2000). Do chimpanzees know what conspecifics do and do not see? *Animal Behavior, 59*, 771-785.

Hare, B., Call, J., & Tomasello, M. (2001). Do chimpanzees know what conspecifics know? *Animal Behaviour, 61*, 139-151.

Johnson, S. (2000). The recognition of mentalistic agents in infancy. *Trends in Cognitive Sciences, 4*(1), 22-28.

Johnson, S., Booth, A., & O'Hearn, K. (2001). Inferring the goals of a nonhuman agent. *Cognitive Development, 16*(1), 637-656.

Johnson, S., Ok, S., & Luo, Y. (2007). The attribution of attention: 9-month-olds' interpretation of gaze as goal-directed action. *Developmental Science, 10*, 530-537.

Johnson, S., Shimizu, Y. A., & Ok, S. J. (2007). Actors and actions: The role of agent behavior in infants' attribution of goals. *Cognitive Development, 22*, 310-322.

Johnson, S., Slaughter, V., & Carey, S. (1998). Whose gaze will infants follow? The elicitation of gaze-following in 12-month-olds. *Developmental Science, 1*, 233-238.

Kamewari, K., Kato, M., Kanda, T., Ishiguro, H., & Hiraki, K. (2005). Six-and-a-half-month-old children positively attribute goals to human action and to humanoid-robot motion. *Cognitive Development, 20*, 303-320.

Király, I., Jovanovic, B., Prinz, W., Aschersleben, G., & Gergely, G. (2003). The early origins of goal attribution in infancy. *Consciousness and Cognition, 12*, 752-769.

Koenig, M., & Harris, P. (2005). Preschoolers mistrust ignorant and inaccurate speakers. *Child Development, 76*, 1261-1277.

Kuhlmeier, V., Wynn, K., & Bloom, P. (2003). Attribution of dispositional states by 12-month-olds. *Psychological Science, 14*, 402-408.

Langton, S. R. H., Watt, R. J., & Bruce, V. (2000). Do the eyes have it? Cues to the direction of social attention. *Trends in Cognitive Sciences, 4*(2), 50-59.

Lee, K., Eskritt, M., Symons, L. A., & Muir, D. (1998). Children's use of triadic eye gaze information for "mind reading". *Developmental Psychology, 34*, 525-539.

Lee, K., & Homer, B. (1999). Children as folk psychologists: The developing understanding of the mind. In A. Slater & D. Muir (Eds.), *The Blackwell Reader in Developmental Psychology* (pp. 228-252). Malden, MA:.

Lempers, J. D., Flavell, E. R., & Flavell, J. H. (1977). The development in very young children of tacit knowledge concerning visual perception. *Genetic Psychology Monographs, 95*, 3-53.

Leslie, A. M. (1995). A theory of agency. In D. Sperber, D. Premack & A. J. Premack (Eds.), *Causal Cognition: A Multidisciplinary Debate*. Oxford, England: Clarendon Press.

Leslie, A. M. (2000). "Theory of mind" as a mechanism of selective attention. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 1235-1247). Cambridges, MA: The MIT Press.

Luo, Y., & Baillargeon, R. (2005). Can a self-propelled box have a goal? *Psychological Science, 16*, 601-608.

Maurer, D., & Barrera, M. (1981). Infants' perception of natural and distorted arrangements of a schematic face. *Child Development, 52*, 196-202.

Meltzoff, A. N. (1995). Understanding the intentions of others: Re-enactment of intended acts by 18-month-old children. *Developmental Psychology, 31*(5), 838-850.

Meltzoff, A. N., & Brooks, R. (2001). "Like me" as a building block for understanding other minds: Bodily acts, attention, and intention. In B. F. Malle (Ed.), *Intentions* *and intentionality: Foundations of social cognition* (pp. 171-191). Cambridge, MA, US: The MIT Press.

Meltzoff, A. N., & Brooks, R. (2007). Eyes wide shut: The importance of eyes in infant gaze-following and understanding others minds. In R. Flom, K. Lee & D. Muir (Eds.), *Gaze Following: Its Development and Significance.* Mahwah, NJ: Lawrence Erlbaum.

Meltzoff, A. N., Gopnik, A., & Repacholi, B. M. (1999). Toddlers' understanding of intentions, desires and emotions: Explorations of the dark ages. In P. D. Zelazo (Ed.), *Developing theories of intention: Social understanding and self control* (pp. 17-41). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Metz, U., Sodian, B., & Poulin-Dubois, D. (2004). *Understanding of the seeing=knowing relation in the second year of life?* Paper presented at the International Conference on Infant Studies, Chicago, Il.

Moll, H., & Tomasello, M. (2004). 12- and 18-month-old infants follow gaze to spaces behind barriers. *Developmental Science, 7*, F1-F9.

Montgomery, D. E., Bach, L. M., & Moran, C. (1998). Children's use of looking behavior as a cue to detect another's goal. *Child Development, 69*, 692-705.

Moore, C. (1999). Gaze-following and the control of attention. In P. Rochat (Ed.), *Early social cognition: Understanding others in the first months of life* (pp. 241-256). Mahwah, NJ: Lawrence Earlbaum.

Moore, C., & Corkum, V. (1994). Social understanding at the end of the first year of life. *Developmental Review, 14*, 349-372.

Moore, C., & Corkum, V. (1998). Infant gaze following based on eye direction. *British Journal of Developmental Psychology, 16*, 495-503.

Morissette, P., Ricard, M., & Gouin-Décarie, T. (1995). Joint visual attention and pointing in infancy: A longitudinal study of comprehension. *British Journal of Developmental Psychology, 13*, 163-175.

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 Development, 72*, 718-735.

O'Neill, D. (1996). Two-year-old children's sensitivity to a parent's knowledge state when making requests. *Child Development, 67*, 659-677.

O'Neill, D., Astington, J. W., & Flavell, J. H. (1992). Young children's understanding of the role that sensory experience play in knowledge acquisition. *Child Development, 63*, 474-490.

Olineck, K. M., & Poulin-Dubois, D. (2005). Infants' ability to distinguish between intentional and accidental actions and its relation to internal state language. *Infancy, 8*, 91-100.

Onishi, K. H., & Baillargeon, R. (2005). Do 15-month-old infants understand false beliefs? *Science, 308*, 255-258.

Perner, J. (1991). *Understanding the representational mind.* Cambridge, MA: The MIT Press.

Perner, J., & Ruffman, T. (2005). Infants' insight into the mind: How deep? *Science, 308*, 214-216.

Phillips, A. T., Wellman, H. M., & Spelke, E. (2002). Infants' ability to connect gaze and emotional expression to intentional action. *Cognition, 85*, 53-78.

Pillow, B. H. (1989). Early understanding of perception as a source of knowledge. *Journal of Experimental Child Psychology, 47*, 116-129.

Poulin-Dubois, D. (1999). Infants' distinction between animate objects and inanimate objects: The origins of naive psychology. In P. Rochat (Ed.), *Early social cognition: Understanding others in the first months of life*. Mahwah, NJ: Lawrence Erlbaum.

Poulin-Dubois, D., Demke, T. L., & Olineck, K. M. (2007). The inquisitive eye: Infants' implicit understanding that looking leads to knowing. In R. Flom, K. Lee & D. Muir (Eds.), *Gaze-following: Its development and significance*. Mahwah, NJ: Lawrence Erlbaum.

Poulin-Dubois, D., Sodian, B., Metz, U., Tilden, J., & Schöppner, B. (2007). Out of sight is not out of mind: Developmental changes in infants' understanding of visual perception during the second year. *Journal of Cognition and Development, 8*, 401-425.

Povinelli, D. J. (2001). On the possibilities of detecting intentions prior to understanding them. In B. F. Malle & L. J. Moses (Eds.), *Intentions and intentionality: Foundations of social cognition* (pp. 225-248). Cambridge, MA: The MIT Press.

Povinelli, D. J., & de Blois, S. (1992). Young children's (Homo sapiens) understanding of knowledge formation in themselves and others. *Journal of Comparative Psychology, 3*, 228-238.

Povinelli, D. J., & Eddy, T. J. (1996). What young chimpanzees know about seeing. *Monographs of the Society for Research in Child Development, 61*(3), v-vi, 1-152.

Povinelli, D. J., & Giambrone, S. (2001). Reasoning about beliefs: A human specialization? *Child Development, 72*, 691-695.

Pratt, C., & Bryant, P. (1990). Young children understand that looking leads to knowing (so long as they are looking into a single barrel). *Child Development, 61*, 973-982.

Repacholi, B. M. (1998). Infants' use of attentional cues to identify the referent of another person's emotional expression. *Developmental Psychology, 34*(5), 1017-1025.

Repacholi, B. M., & Gopnik, A. (1997). Early reasoning about desires: Evidence from 14- and 18-month-olds. *Developmental Psychology, 33*, 12-21.

Ruffman, T., & Olson, D. R. (1989). Children's ascriptions of knowledge to others. *Developmental Psychology, 25*, 601-606.

Sabbagh, M., & Baldwin, D. A. (2001). Learning words from knowledgeable versus ignorant speakers: Link between preschoolers' theory of mind and semantic development. *Child Development, 72*, 1054-1070.

Scaife, M., & Bruner, J. S. (1975). The capacity for joint visual attention in the infant. *Nature, 253*, 265-266.

Shimizu, Y. A., & Johnson, S. (2004). Infants' attribution of a goal to a morphologically unfamiliar agent. *Developmental Science, 7*(4), 425-430.

Sodian, B., & Thoermer, C. (2004). Infants' understanding of looking, pointing and reaching as cues to goal-directed action. *Journal of Cognition and Development, 5*, 289-316.

Sodian, B., Thoermer, C., & Metz, U. (2007). Now I see it but you don't: 14-month-olds can represent another person's visual perspective. *Developmental Science, 10*, 199-204.

Southgate, V., Senju, A., & Csibra, G. (2007). Action anticipation through attribution of false belief by 2-year-olds. *Psychological Science, 18*, 587-592.

Surian, L., Caldi, S., & Sperber, D. (2007). Attribution of beliefs by 13-month-old infants. *Psychological Science, 18*, 580-586.

Tomasello, M. (1995). Joint attention as social cognition. In C. Moore & P. Dunham (Eds.), *Attention: Its Origins and Role in Development*. Hillsdale, NJ: Lawrence Earlbaum.

Tomasello, M. (1999). Having intentions, understanding intentions, and understanding communicative intentions. In P. D. Zelazo, J. W. Astington & D. R. Olson (Eds.), *Developing Theories of Intention: Social understanding of self control* (pp. 63-75). Mahwah, NJ: Erlbaum.

Tomasello, M. (2001). Perceiving intentions and learning words in the second year of life. In M. Bowerman & S. C. Levinson (Eds.), *Language acquisition and conceptual development*. Cambridge, UK: Cambridge University Press.

Tomasello, M., & Haberl, K. (2003). Understanding attention: 12- and 18-month-olds know what is new for other persons. *Developmental Psychology, 39*, 906-912.

Tremoulet, P. D., & Feldman, J. (2000). Perception of animacy from the motion of a single object. *Perception, 29*, 943-951.

Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development, 72*(3), 655-684.

Wimmer, H., Hogrefe, G. J., & Perner, J. (1988). Children's understanding of informational access as a source of knowledge. *Child Development, 59*, 386-396.

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition, 69*, 1-34.

Woodward, A. L. (2003). Infants' developing understanding of the link between looker and object. *Developmental Science, 6*(3), 297-311.

Woodward, A. L. (2004). Infants' use of action knowledge to get a grasp on words. In D. G. Hall & S. R. Waxman (Eds.), *Weaving a Lexicon* (pp. 149-169). Cambridge, MA: The MIT Press.

Woodward, A. L., Sommerville, J. A., & Guajardo, J. J. (2001). How infants make sense of intentional action. In B. F. Malle, L. J. Moses & D. A. Baldwin (Eds.), *Intentions and Intentionality: Foundations of Social Cognition*. Cambridge, MA: The MIT Press.

Woolley, J. D., & Wellman, H. M. (1993). Origin and truth: Young children's understanding of imaginary mental representations. *Child Development, 64*, 1-17.

Appendix A

Sample Recruitment Letter, Parent Consent Form, and Participant Information Form

(Chapter 2, Experiment 3)

June 2003

Dear parents,

The Child Development Laboratory at Concordia University is completing a series of studies investigating what infants know about people and objects. This research is funded by the Natural Sciences and Engineering Research Council of Canada. The Commission d'Accès à l'Information du Québec has kindly given us permission to consult birthlists provided by the Régie Régionale de la Santé et des Services Sociaux de la Région de Montréal-Centre. Your name appears on the birthlist of January 2002, indicating that you have an infant of an appropriate age for our study.

The present study involves examining infants' ability to understand the link between people's eye gaze and knowledge. In this task, we will show your infant a series of movies in which a pair of actors are playing a game that involves finding the location of a hidden toy. In the movies, an actor is asked to find a toy that was placed under one of two buckets. In some instances the actor saw where it was hidden, while in other cases she was blindfolded. We will then show your infant still frames of the actor's search for the hidden toy, and measure the amount of time they look at each still frame. If infants understand that seeing leads to knowing, we expect that they will be surprised (i.e., look longer) when the actor who was blindfolded finds the toy in the correct location. During the entire study, your infant will be sitting in a child seat and you will be seated directly behind him or her. The session with your infant will be videotaped and all tapes will be treated in the strictest of confidentiality.

Your participation would involve a visit of approximately 45 minutes to our research centre on the Loyola Campus of Concordia University, located at 7141 Sherbrooke Street West. Appointments can be scheduled at a time convenient to you, including weekends. Free parking is available on the campus, and we will gladly reimburse any transportation expenses at the time of your appointment. Upon completion of the study, a Certificate of Merit and toy prize will be given to your child, and a report of the results of the study will be mailed to you as soon as it is available.

For the purpose of the this study, we are looking for infants whose parents speak English or French at home, and who have no visual or auditory difficulties. If you are interested in having your child participate in this study, or would like further information, please contact Tamara Demke or Renée St-Pierre at 848-2279. We will attempt to contact you by telephone within a few weeks of your receipt of this letter.

Thank you for your interest and collaboration,

Diane Poulin-Dubois, Ph. D.	Tamara Demke, M.A.	Renée St-Pierre
Professor	Graduate Student	Research Assistant
Department of Psychology	Department of Psychology	Department of Psychology

Parental Consent Form

The present experiment examines infants' ability to understand the link between people's eye gaze and knowledge. To do this, we will show your infant a series of movies in which a pair of actors are playing a game that involves finding the location of a hidden toy. In the movies, an actor is asked to find a toy that was placed under one of two buckets. In some instances the actor saw where it was hidden, while in other cases she was blindfolded. We will then show your infant still frames of the actor's search for the hidden toy, and measure the amount of time they look at each still frame. You will be present throughout the experimental session but we ask that you remain silent and neutral. The entire session will be videotaped. The videotapes, and data obtained from the tapes, will be kept strictly confidential. The entire session is expected to last approximately 45 minutes.

______________________	______________________	______________________
Diane Poulin-Dubois, Ph. D.	Tamara Demke, M.A.	Renée St-Pierre
Professor	Graduate Student	Research Assistant
Department of Psychology	Department of Psychology	Department of Psychology

The nature and purpose of this study have been satisfactorily explained to me and I agree to allow my child to participate. I understand that we are free to discontinue participation at any time without negative consequences and that the experimenter will gladly answer any questions that might arise during the course of the research.

______________________ ______________________

Parent's signature Date

I would be interested in participating in other studies with my child in the future:
(yes/ no): _____

Participant # ____________ Researcher: _______________

Participant Information

Infant's first name:________________________ Date of Birth: ________________________________

Infant's last name:_____________________ Gender:__________

Language(s) spoken at home:___________________________________

Mother's first name: _____________________ Father's first name: ________________

Mother's maiden name:________________ Father's last name: ____________________________

Address: __________________________________ Telephone #: ________________________home

__________________________________ ________________________work mom

Postal Code:____ ________________________work dad

e-mail____________________________

Mother's occupation:_________________ Father's occupation:_________________

Mother's education (highest level attained):____

Father's education (highest level attained):____

Mother's marital status:_______________________ Father's marital status:_______________________

Please answer the following general information questions about your child:

Birth weight:______________________ Length of pregnancy:________weeks

Birth order:______________________(e.g., 1 = 1st child)

Number of siblings:_________________

Were there any complications during the pregnancy?____

Has your child had any major medical problems?____

Does your child have any hearing or vision problems? _______________________________________

Please answer the following general information questions about your family:

Does your family have a pet (or pets)? (yes/no) ______

If you answered yes, please list your pet(s) indicating the kind of pet(s) (e.g., dog, cat, fish) and the number of pets:

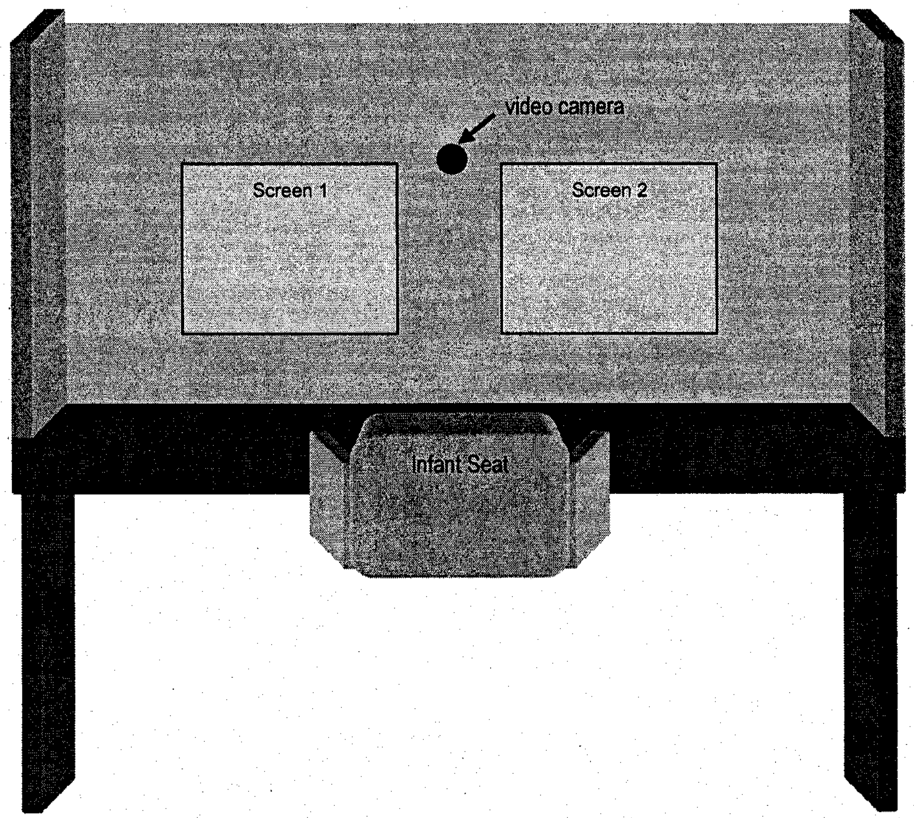
____

Participant#:_______________ Researcher:________________________________

Appendix B

Preferential Looking Paradigm Apparatus

(Chapter 2, Experiment 3)


video camera
Screen 1
Screen 2
Infant Seat

Appendix C

Sample Instructions Provided to Parents

(Chapter 2, Experiment 3)

Instructions for Parents

1. When we enter the room where we will be doing the study, please seat your child in the infant seat and sit behind your child in the chair provided.

2. Before we begin the task, please ensure that your child has no toys or food, as these items may be distracting.

3. During the study, please do not interact with your child. Please do not point at the computer screens or speak to your child.

4. As you will be sitting behind your child, you will be able to see what is being presented to your child but not where your child is looking. Although this may be frustrating, please do not move to try to see your child's reactions during the study.

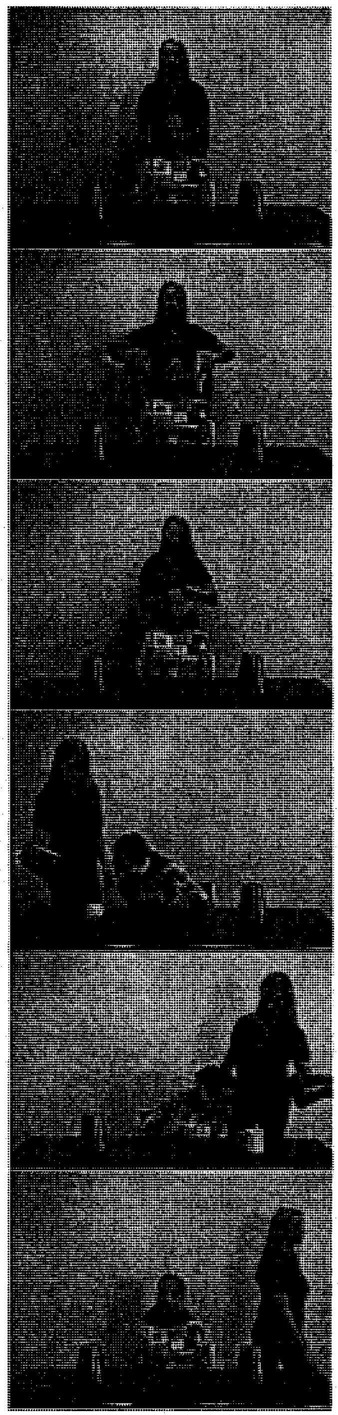
5. Children often look away from the computer screen from time to time during the study. If your child turns to look at you, please **ONLY** smile at him/her. Your child will probably turn to look at the computer screens after a moment.

6. If your child becomes very fussy or starts to cry, we will stop the study so that you can comfort him/her.

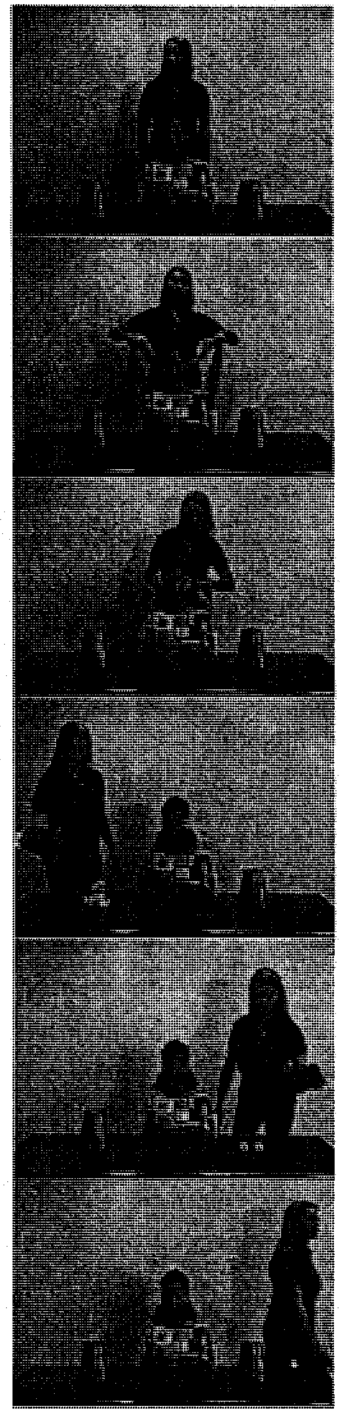
Appendix D

Still Frames from Movies used in the Preferential Looking Paradigm

(Chapter 2, Experiment 3)

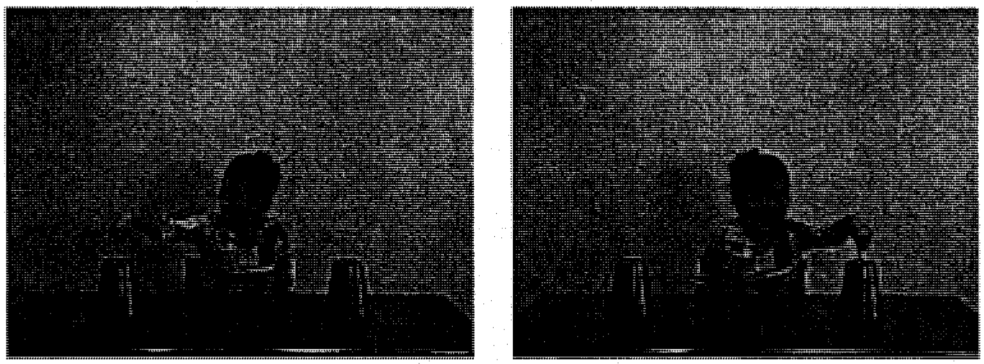


Visual Access



No Visual Access

Still frames from movies presented in the information phase.



Still frames presented to infants in the test phase.

Appendix E

Analysis of Variance for Condition (Eyes Open, Eyes Blindfolded)

by Action (Correct, Incorrect) in Experiment 3

(Chapter 2)

Analysis of Variance for Condition (Eyes Open, Eyes Blindfolded) by Action (Correct, Incorrect) in Experiment 3 (Chapter 2)

Source	*df*	*F*
Within subjects		
Condition	1	4.25
Action	1	0.53
Condition x Action	1	0.50
Within-group error	26	(3.33)

Note. Values enclosed in parentheses represent mean square errors.

Appendix F

Sample Recruitment Letter, Parent Consent Form, and Participant Information Form

(Chapter 3)

December 2004

Dear parents,

The Child Development Laboratory at Concordia University is involved in a series of studies looking at infants' understanding of human eyes and how they play an important role in informing us about another person's mental states. This research is funded by the Social Sciences and Humanities Research Council of Canada. The Commission d'Accès à l'Information du Québec has kindly given us permission to consult birthlists provided by the Régie Régionale de la Santé et des Services Sociaux de la Région de Montréal-Centre. Your name appears on the birthlist of May 2003, which indicates that you have a child of an age appropriate for our study.

The present investigation involves two tasks. In one task, we are examining infants' ability to understand the link between eye gaze and knowledge acquisition. In this task, we will show your child a series of movies in which a pair of actors are playing a game that involves finding the location of a hidden toy. In the movies, an actor is asked to find a toy that was placed underneath one of two buckets. In some instances the actor saw where the toy was hidden, while in other cases she was blindfolded. We will then show your child still frames of the actor's search for the hidden toy, and record the amount of time they look at each still frame. If young children understand that seeing leads to knowledge, we expect that they will be surprised (i.e., look longer) when the actor who was blindfolded finds the toy in the correct location. The other task has been designed to examine how infants interpret a speaker's actions when they are learning a new word. Your child will hear a new word as he or she is looking at unfamiliar objects. The speaker will either look directly at the object your child is looking at, or will look at a different object when she utters a new word. Later, your child will be asked to find one of the objects. Furthermore, to provide us with information about how infants understand the unique nature of human eyes, we are also completing the above tasks with a computerized robot. We are interested in whether infants will treat the human and the robot differently across these tasks. During both studies, your child will be sitting in a child seat and you will be seated directly behind. We will videotape your child's responses and all tapes will be treated in the strictest of confidentiality.

Participation involves one visit of approximately 45 minutes to our research centre on the Loyola Campus of Concordia University, located at 7141 Sherbrooke Street West. Appointments can be scheduled at a time convenient to you, including weekends. Free parking is available on the campus for our participants, and we will gladly reimburse any transportation expenses at the time of your appointment. Upon completion of the study, a Certificate of Merit will be given to your child, and a report of the results of the study will be mailed to you as soon as it is completed.

For the purpose of the this study, we are looking for infants whose parents speak French or English at home, and who have no visual or auditory difficulties. If you are interested in having your child participate in this study, or would like further information, please contact Tamara Demke or Sandra Misrachi at 848-2424 ext. 2279. We will attempt to contact you by telephone after receipt of this letter.

Thank you for your collaboration,

Diane Poulin-Dubois, Ph. D.
Professor
Department of Psychology

Tamara Demke, M.A.
Ph.D. Candidate

Sandra Misrachi, B.A.
Research Assistant

(français au verso)

Parental Consent Form

The present investigation involves two parts. The first part involves examining infants' ability to understand the link between eye gaze and knowledge. In this task, we will show your child a series of movies in which a pair of actors are playing a game that involves finding the location of a hidden toy. In the movies, an actor is asked to find a toy that was placed underneath one of two buckets. In some instances the actor saw where the toy was hidden, while in other cases she was blindfolded. We will then show your child still frames of the actor's search for the hidden toy, and measure the amount of time they look at each still frame. If young children understand that seeing leads to knowledge, we expect that they will be surprised (i.e., look longer) when the actor who was blindfolded finds the toy in the correct location. The second task has been designed to examine how infants interpret a speaker's actions when they are learning a new word. Your child will hear a new word as they are looking at unfamiliar objects. The speaker will either look directly at the object your child is looking at, or will look at a different object when she utters a new word. Later, your child will be asked to find one of the objects. Furthermore, to provide us with information about how infants understand the unique nature of human eyes, we are also completing the above tasks with a computerized robot. In these studies, infants will observe the robot looking at the different objects, and they will hear the robot utter the new word. We are interested in whether infants will treat the human and the robot differently across these tasks. You will be present throughout the experimental session, but we ask that you remain silent and neutral. We will videotape your child's responses and all tapes will be treated in the strictest of confidentiality. The entire session is expected to last approximately 45 minutes.

______________________	______________________	______________________
Diane Poulin-Dubois, Ph.D. Professor Department of Psychology	Tamara Demke, M.A. Ph.D. Candidate	Sandra Misrachi, B.A. Research Assistant

The nature and purpose of this study have been satisfactorily explained to me and I agree to allow my child to participate. I understand that we are free to discontinue participation at any time without negative consequences and that the experimenter will gladly answer any questions that might arise during the course of the research.

______________________ ______________________
Parent's signature Date

I would be interested in participating in other studies with my child in the future (yes/ no): _____

Participant # ____________ Researcher: __________________

Participant Information

Infant's first name:____________________ Date of Birth: ____________________________

Infant's last name:____________________ Gender:____________

Language(s) spoken at home:__________________________________

Mother's first name: ________________________ Father's first name: ___________________

Mother's maiden name:________________ Father's last name: _________________________

Address: ____________________________ Telephone #: ___________________home

_________________________________ ___________________work mom

Postal Code:______________________________ ___________________work dad

e-mail___________________________

Mother's occupation:____________________ Father's occupation:________________________

Mother's education (highest level attained):____

Father's education (highest level attained):____

Mother's marital status:__________________ Father's marital status:________________

Please answer the following general information questions about your child:

Birth weight:___________________ Length of pregnancy:____________weeks

Birth order:____________________(e.g., 1 = 1st child)

Number of siblings:______________

Were there any complications during the pregnancy?_______________________________________

Has your child had any major medical problems?____________________________________

Does your child have any hearing or vision problems? __________________________________

Please answer the following general information questions about your family:

Does your family have a pet (or pets)? (yes/no) ______

If you answered yes, please list your pet(s) indicating the kind of pet(s) (e.g., dog, cat, fish) and the number of pets:

____

Does your child have any experience with remote-controlled toys (e.g., car, robot)? (yes/no) ________

If you answered yes, please indicate the kind of remote-controlled toy: ________________________

Participant#:____________ Researcher:___________________

Appendix G

Analysis of Variance for Condition (Eyes Open, Eyes Blindfolded) by Agent (Person, Robot) by Order (First trial is Eyes Open, First Trial is Eyes Blindfolded) for Information Phase Trials

(Chapter 3)

Analysis of Variance for Condition (Eyes Open, Eyes Blindfolded) by Agent (Person, Robot) by Order (First trial is Eyes Open, First Trial is Eyes Blindfolded) for Information Phase Trials (Chapter 3)

Source	*df*	*F*
Between subjects		
Agent	1	0.02
Order	1	3.82
Agent x Order	1	0.58
Within-group error	51	(59.60)
Within subjects		
Condition	1	0.99
Condition x Agent	1	0.02
Condition x Order	1	0.42
Condition x Agent x Order	1	4.77*
Within-group error	51	(19.96)

Note. Values enclosed in parentheses represent mean square errors. * $p < .05$.

Appendix H

Analysis of Variance for Condition (Eyes Open, Eyes Blindfolded) by Agent (Person, Robot) by Screen (Correct, Incorrect) for Test Phase Trials, $N = 55$ (Chapter 3)

Analysis of Variance for Condition (Eyes Open, Eyes Blindfolded) by Agent (Person, Robot) by Screen (Correct, Incorrect) for Test Phase Trials, $N = 55$ (Chapter 3)

Source	*df*	*F*
Between subjects		
Agent	1	1.43
Within-group error	53	(7.04)
Within subjects		
Condition	1	1.60
Condition x Agent	1	4.50*
Screen	1	0.11
Screen x Agent	1	2.23
Condition x Screen	1	1.08
Condition x Screen x Agent	1	0.30
Within-group error	53	(10.64)

Note. Values enclosed in parentheses represent mean square errors. * $p < .05$.

Appendix I

Analysis of Variance for Condition (Eyes Open, Eyes Blindfolded) by Agent (Person, Robot) by Screen (Correct, Incorrect) for Test Phase Trials, $N = 38$

(Chapter 3)

Analysis of Variance for Condition (Eyes Open, Eyes Blindfolded) by Agent (Person, Robot) by Screen (Correct, Incorrect) for Test Phase Trials, $N = 38$ (Chapter 3)

Source	*df*	*F*
Between subjects		
Agent	1	13.76
Within-group error	36	(6.32)
Within subjects		
Condition	1	0.52
Condition x Agent	1	3.91*
Screen	1	0.02
Screen x Agent	1	3.83*
Condition x Screen	1	0.66
Condition x Screen x Agent	1	0.14
Within-group error	36	(12.05)

Note. Values enclosed in parentheses represent mean square errors. * $p < .05$.

Appendix J

Sample Recruitment Letter, Parent Consent Form, and Participant Information Form

(Chapter 4)

December 2004

Dear parents,

The Child Development Laboratory at Concordia University is involved in a series of studies looking at infants' understanding of human eyes and how they play an important role in informing us about another person's mental states. This research is funded by the Social Sciences and Humanities Research Council of Canada. The Commission d'Accès à l'Information du Québec has kindly given us permission to consult birthlists provided by the Régie Régionale de la Santé et des Services Sociaux de la Région de Montréal-Centre. Your name appears on the birthlist of May 2003, which indicates that you have a child of an age appropriate for our study.

In the present experiment, we are examining how infants interpret a speaker's actions when they are learning a new word. Your child will hear a new word as he or she is looking at unfamiliar objects. The speaker will either look directly at the object your child is looking at, or will look at a different object when she utters a new word. Later, your child will be asked to find one of the objects. Furthermore, to provide us with information about how infants understand people and inanimate objects, we are also completing the above tasks with a computerized robot. We are interested in whether infants will treat the human and the robot differently. During both studies, your child will be sitting in a child seat and you will be seated directly behind. We will videotape your child's responses and all tapes will be treated in the strictest of confidentiality.

Participation involves one visit of approximately 45 minutes to our research centre on the Loyola Campus of Concordia University, located at 7141 Sherbrooke Street West. Appointments can be scheduled at a time convenient to you, including weekends. Free parking is available on the campus for our participants, and we will gladly reimburse any transportation expenses at the time of your appointment. Upon completion of the study, a Certificate of Merit will be given to your child, and a report of the results of the study will be mailed to you as soon as it is completed.

For the purpose of the this study, we are looking for infants whose parents speak French or English at home, and who have no visual or auditory difficulties. If you are interested in having your child participate in this study, or would like further information, please contact Tamara Demke or Sandra Misrachi at 848-2424 ext. 2279. We will attempt to contact you by telephone after receipt of this letter.

Thank you for your collaboration,

Diane Poulin-Dubois, Ph. D.
Professor
Department of Psychology

Tamara Demke, M.A.
Ph.D. Candidate

Sandra Misrachi, B.A.
Research Assistant

(français au verso)

Parental Consent Form

The present investigation examines how infants interpret a speaker's actions when they are learning a new word. Your child will hear a new word as they are looking at unfamiliar objects. The speaker will either look directly at the object your child is looking at, or will look at a different object when she utters a new word. Later, your child will be asked to find one of the objects. Furthermore, to provide us with information about how infants understand people and inanimate objects, we are also completing the above tasks with a computerized robot. In these studies, infants will observe the robot looking at the different objects, and they will hear the robot utter the new word. We are interested in whether infants will treat the human and the robot differently. You will be present throughout the experimental session, but we ask that you remain silent and neutral. We will videotape your child's responses and all tapes will be treated in the strictest of confidentiality. The entire session is expected to last approximately 45 minutes.

______________________	______________________	______________________
Diane Poulin-Dubois, Ph.D.	Tamara Demke, M.A.	Sandra Misrachi, B.A.
Professor	Ph.D. Candidate	Research Assistant
Department of Psychology		

The nature and purpose of this study have been satisfactorily explained to me and I agree to allow my child to participate. I understand that we are free to discontinue participation at any time without negative consequences and that the experimenter will gladly answer any questions that might arise during the course of the research.

______________________ ______________________

Parent's signature Date

I would be interested in participating in other studies with my child in the future (yes/ no): _____

Participant # ____________ Researcher: ________________

Participant Information

Infant's first name:____________________ Date of Birth: ____________________________

Infant's last name:____________________ Gender:____________

Language(s) spoken at home:__________________________________

Mother's first name: ______________________ Father's first name: __________________

Mother's maiden name:________________ Father's last name: _________________________

Address: ____________________________ Telephone #: ____________________home

_________________________________ ____________________work mom

Postal Code:_________________________________ ____________________work dad

e-mail___________________________

Mother's occupation:____________________ Father's occupation:________________________

Mother's education (highest level attained):____

Father's education (highest level attained):____

Mother's marital status:__________________ Father's marital status:________________

Please answer the following general information questions about your child:

Birth weight:___________________ Length of pregnancy:_____________weeks

Birth order:____________________(e.g., 1 = 1st child)

Number of siblings:______________

Were there any complications during the pregnancy?_______________________________________

Has your child had any major medical problems?__________________________________

Does your child have any hearing or vision problems? __________________________________

Please answer the following general information questions about your family:

Does your family have a pet (or pets)? (yes/no) ______

If you answered yes, please list your pet(s) indicating the kind of pet(s) (e.g., dog, cat, fish) and the number of pets:

____

Does your child have any experience with remote-controlled toys (e.g., car, robot)? (yes/no) ________

If you answered yes, please indicate the kind of remote-controlled toy: _______________________

Participant#:____________ Researcher:__________________