

Theoretical note

Two-levels of mental states attribution: from automaticity to voluntariness

Giorgio Coricelli*

Institut des Sciences Cognitives, CNRS 67, Boulevard Pinel 69675, Bron, France

Abstract

In this paper, I introduce the hypothesis that there are two levels of mindreading. The first level refers to automatic-preconceptual phenomena that specify a primitive understanding of another person's mind. It is based on early-imitation, action and emotion recognition. The second level of mindreading is conceptual and voluntary. It is based on intentionality, empathy, and higher depths of reasoning. The activities in both levels are generated by internal simulative mechanisms. This hypothesis is based on human and nonhuman neuroscientific evidence.

© 2004 Elsevier Ltd. All rights reserved.

Keywords: Theory of mind; Simulation theory

1. Introduction

The complexity of the processes underlining social interaction is often underestimated in the neuroscientific literature. An advanced mechanism of mindreading, needed for the understanding and the interpretation of others' intentions and behavior in terms of their mental states, requires a correspondent sophisticated neural mechanism.

The domain specificity of mindreading is also often unconsidered. We cannot assume that there is a unique brain module that is always implemented and solves the many possible social interactive situations.

In this paper, I consider mindreading system as a domain specific mechanism that evolves from a more basic, but specialized form of social cognition, to a more sophisticated form of intersubjectivity.

I introduce two-levels of understanding of others' intentions and behaviors. The first level of this model refers to automatic preconceptual phenomena that specify a primitive understanding of another person's mind. The second level of mindreading is conceptual and voluntary. The acquisition of the second level implies the ability to adopt the perspective

of the other person in the understanding and predicting of behavior.

In my analysis, I consider that the processes involved in the attribution of mental states are simulations; simulation being any brain activity related to preceding or non-executed actions.

The goal of this paper is to define a plausible relationship between the two levels of mindreading. I present a description of the first level and I conclude with some considerations about its link with the second level. In support of this hypothesis, I present evidence coming from non-human primates investigations, as well as data obtained in neuropsychological and neuroimaging studies in human subjects.

2. The first level of understanding of mind

I consider two systems as part of the first level of the mindreading model. The first system enables a primordial understanding of intentions through movement observation and the second system is based on emotion recognition and emotional contagion. Both systems contribute to generate a more sophisticated simulative mechanism that underlines a higher level of the mindreading process. Thus, the claim of this paper is that action-recognition and emotion-recognition are the basis for mindreading development.

* Tel.: +33 4 37911249; fax: +33 4 37911210.
E-mail address: coricelli@isc.cnrs.fr.

2.1. Action recognition

The understanding of how people infer the intentions of others from their movements is a crucial point for the definition of a primitive level of mindreading. The extraordinary human and non-human ability to recognize and identify movement of living things and, in particular, movement of their conspecifics, namely ‘biological motion’, shows that there is something unique in their movements. Animate and deliberate movements have specific aspects that can be inferred and interpreted by the observer. We need few cues, few points of light attached to the joints of the person moving, to recognize human actions (Johansson, 1973).

Results from neuroimaging studies indicate that the superior temporal sulcus (STS) is the region of the brain specialized to distinguish biological from non-biological motion in moving things (Bonda, Petrides, Ostry, & Evans, 1996; Grezes, Costes, & Decety, 1998; Grezes et al., 2001; Vaina, Solomon, Chowdhury, Sinha, & Belliveau, 2001; Grossman & Blake, 2002; Pelphrey et al., 2003; for review see Decety & Grezes, 1999; Allison, Puce, & McCarthy, 2000). This region is distinct from the usual “motion” areas MT and V5, thus indicating a specialization of the brain in responding to biological motion.

Most of these imaging studies are simulations of biological motion with point-light display, where few isolated points of light are attached to major points of the body, and control for non-biological motion with random or noncoherent motion.

The experiment by Bonda et al. (1996) investigates two types of motions: (1) goal-directed action of the hand, imitation of the act of reaching for a glass, picking it up, and bringing it to the mouth; (2) movement of the whole body, e.g. expressive dancing-like movement. The first type of motion activates areas in the posterior part of the left hemisphere within the intraparietal sulcus and the caudal superior temporal sulcus. The perception of expressive body movements activates the temporal neocortex and limbic areas (amygdala) critical for emotions. These results show the existence of different mechanisms for the perceptual analysis of different categories of movements involving biological motion, and the specificity of a perception mechanism for goal-directed action.

There is also evidence of specialization in responding to other types of biological movements, like mouth movement (Puce, Allison, Bentin, Gore, & McCarthy, 1998), lip movement (Calvert et al., 1997), and walking (Pavlova, Lutzenberger, Sokolov, & Birbaumer, 2004). In particular, the result of this last study shows the early stage of cortical processing in discriminating between canonical and scramble-walking movement indicating the automaticity of this selective response.

Developmental studies show that the predisposition for detecting biological motion is present in infants of 4–6 months (Fox & McDaniel, 1982).

In summary, the data described above shows that the ability of recognizing action of other humans is innate and auto-

matic, and secondly, that it is specialized for different categories, including goal-directed actions.

The characteristic movements of living things, called ‘biological motion’, (Johansson, 1973) expresses intentions. Therefore, the existence of specialized brain circuits that detect biological motion is *prima facie* evidence of the existence of mechanisms specialized for the attribution of intentions (Castelli, Happe, Frith, & Frith, 2000; Blakemore & Decety, 2001; Blakemore et al., 2001).

2.2. From action recognition to action generation. *Connecting the external with the internal world: the mirror effect*

My model for describing how people infer the intentions of others from their actions is a system defined by two mechanisms. The first mechanism is driven by the ‘biological motion neurons’ that responds automatically to externally generated movements, distinguish and isolate intentional motion from general motion. The second component of the system is represented by the ‘mirror neurons’.

The mirror neurons have been discovered in the inferior frontal cortex of monkeys (inferior premotor area F5). These cells are active when the monkey makes a goal-oriented movement (e.g. grasping food) and when the monkey observes the experimenter or another monkey executing the same movement (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996a).

This cortical circuit represents a system that has the function of matching action observation and execution, where the observation of an action automatically activates neurons that are usually active while executing the same action (Gallese et al., 1996; Rizzolatti et al., 1996b).

First evidence of the presence of the mirror system in human was found using Transcranial Magnetic Stimulation in a study conducted by Fadiga, Fogassi, Pavesi, and Rizzolatti (1995).

Grafton, Arbib, Fadiga, and Rizzolatti (1996) identified areas of the brain involved in movement planning by requiring subjects to imagine performing grasping. The process of imagining the execution of the task (grasping) is similar to the process of preparation for the real movements.

This mental task activates the lateral premotor cortex and supplementary motor area (SMA), which has been functionally subdivided (as described in Grafton et al., 1996) in supplementary motor area rostral (SMAR) and supplementary motor area caudal (SMAC). The SMAR refers to movement planning estimated by imagined movements and the SMAC refers to movement execution. Observing another person making a grasping movement activates motor areas that may be involved in planning a similar action. This effect is also called the ‘mirror effect’ (Rizzolatti et al., 1996a).

There are two main characteristics of mirror neurons. First, the mirror neurons refer to goal-related movements. These cells are selectively active during the execution and

observation of goal-related movements thereby representing a link between external generated goal-oriented movements and similar internal generated movements. Second, the mirror neurons are activated automatically. The automatic nature of the mirror neurons is shown in the data collected by Fadiga et al. (1995) in an experiment on humans. These data show that the brain cannot inhibit the increase of motor evoked potentials (MEPs) during observation of movements. The inability of the brain to inhibit this type of reaction shows the automatic nature of the mirror effect.

The existence of the mirror neurons indicates the ability of the brain to replicate and mimic the action of the target and to recognize the intention of the action. The discovery of mirror neurons provides the first evidence of the presence of an internal representation of the goals and intentions of the others in the brain.

Partially in contrast with the seminal paper of Gallese and Goldman (1998), I assume an unambiguous position in considering the mirror neurons only as precursor and not as part of a more general mindreading ability (second level of my model). This statement is motivated by the nature of the simulative process related to action observation that characterizes mirror neurons, which is automatic, unconscious, prereflexive and local (Gallese, 2003). These characteristics of the simulative process limit the role of the mirror neurons as precursors of a complete mindreading mechanism because those characteristics do not fulfill necessary conditions for a sophisticated mindreading process. In order to enable processes of definition and acquisition of mental categories, in the case of mindreading mental state categories, the simulation process need to implement different and connected mechanisms, such as anticipation, self sustained inner loops and reactivation. I will come back to this point further in the paper.

In synthesis mirror neurons match observation of external movement with internal represented movements. The result of the recognition also represents an input for a motor-facilitation system, based on imitation, and represents an input for an interpretation-of-action system (Jeannerod, 2001). Thus, the main function of the mirror neurons is to represent actions for imitating and for understanding them. This particular ability is vital for all of the animals that need to assign meaning to social events that may be rather similar in their sensory aspects.

2.3. *Emotion recognition and emotional contagion*

Perception of emotion is part of the first level of the mindreading system. The emotional system links the infant to the caregiver since the beginning of life (Stern, 1977; Stern, 1985; Baron-Cohen, 1995). The facial expression is the main instrument of 'emotion contagion' and arises when an agent reads the affection of another and imitates (Meltzoff & Moore, 1977; Meltzoff & Moore, 1983; Meltzoff & Moore, 1989) the affective position. An example of emotional contagion presented early in life is the baby that cries when another baby is crying. Within the face, the eyes are the most impor-

tant contact between agents (Maurer, 1985; Haith, Bergman, & Moore, 1977; Hainline, 1978). Eye contact determines increase in physiological arousal. Nichols and Champness (1971) report evidence of an increase of skin conductance responses (SCRs) during eye contact. Eye contact embedded mostly positive emotions, which for example result in smiling (Wolff, 1963; Schaffer, 1977). The infant seems to have an innate predisposition for looking at the eyes and direct their attention to mutual eye gaze (Farroni, Csibra, Simion, & Johnson, 2002). This predisposition stimulates unconscious emotional experiences (Maurer, 1993). Mutual gaze is correlated with the baby smiling; indeed, when the adult averts her gaze the baby tends to reduce or stop smiling (Hains & Muir, 1996).

The neural system underlying the ability to process another person's eye gaze refers to the superior temporal sulcus and the medial prefrontal cortex (Calder et al., 2002). These two regions are also involved in mindreading (for a review of imaging data on theory of mind, Gallagher & Frith, 2003). Thus, emotional recognition seems to be linked to the process of attribution of mental states.

Amygdala is also involved in perceptual tasks requiring recognition of facial expression, and several general functions within the domain of emotion and social behavior (Adolphs, Tranel, & Baron-Cohen, 2002; Adolphs, Tranel, & Damasio, 1998; Adolphs, Tranel, Damasio, & Damasio, 1994). There is imaging and clinical (Baron-Cohen et al., 1999; Stone, Baron-Cohen, Calder, Keane, & Young, 2003) evidence that shows how the amygdala regions represent an important input for the mindreading system. The imaging study (fMRI) by Baron-Cohen et al. (1999) shows amygdala activation in normal subjects performing the 'Reading the Mind in the Eyes Task', inferring complex mental states from images of the eyes. A more recent study conducted by Shaw et al. (2004) compares performance on theory of mind tasks of two groups of patients, respectively, with early or acquired amygdala damages. Evidence from this study indicates that only the early damaged patients are impaired in theory of mind. This result shows how the amygdala has essentially a developmental role in the acquisition of the mindreading system.

In summary, recognition of emotions and the emotional contagion are two primitive forms of social communication. First, the baby recognizes and imitates the affective expression of others, and then the baby can simulate the affective position. Additionally, the natural tendency of the caregiver to attribute intentions to the baby represents a first 'attitude (e.g. crying) therefore consequence (care of the mother)' experience. This type of interaction, namely the caregiver attributing intention to the baby's emotion, stimulates the baby's understanding and expression of intentions.

3. From the first to the second level of mindreading

I consider the mindreading system as a domain specific mechanism. This system evolves from a more basic,

but specialized form of social cognition—perception of intention from movements, perception of emotion and emotional contagion—(first level) to a more sophisticated form of ‘mind–mind’ interaction (second level). The first level of mindreading is automatic and preconceptual while the second is voluntary and conceptual.

I suggest that both levels present the distinction between ‘cold’ and ‘hot’ aspects of mindreading (Brothers & Ring, 1992). The cold aspects refer to inferences concerning epistemic states (beliefs, desires and knowledge), while the hot aspects refer to inferences about others’ affective states.

The first level represents the basis for the mindreading development. Processes of early imitation and learning of social skills are involved at this first level. Indeed, the ability to imitate is present also in infants (Meltzoff & Moore, 1977; Meltzoff & Moore, 1983; Meltzoff & Moore, 1989). This ability is expressed in the imitation of facial and manual gestures. This type of imitation involves a mechanism that maps the externally generated action onto an internal motor representation of the same action, called ‘resonance mechanism’ by Rizzolatti et al. (1999). There is a progression from this simple and automatic imitation to the understanding and execution of intention-related action. Therefore, early imitation mechanisms contribute to the development of a more sophisticated mindreading system. The main contribution of early imitation consists on stimulating the understanding of the ‘like me’ in the other-self relationship (Meltzoff & Decety, 2003; Gallese, 2003; Iacoboni et al., 1999).

With concern emotions, there is a progression from an automatic-unconscious contagion mechanism to a conscious and volitional expression of emotion. This path progressively implements a greater degree of definition and integration of the schemata used to process emotional information coming from internal or external emotional experience. The intersubjectivity in terms of emotions is based on the emphatic process.

Empathy is based on common experience of action between self and the other (Gallese, 2003). The empathic process involves a simulation of the affective situation of the other person with the goal of understanding her emotional status. Evidence of the neural basis of the process that modulates empathy from action representation is described in the neuroimaging study of Carr et al. (2003). This study shows the crucial role of the insula for transferring salient emotional information, derived from action representation, to the limbic areas.

3.1. *Simulation processes involved in the two levels of mindreading*

Internal simulation processes characterize both levels of mindreading. The different nature of those processes determines the distinctions between the two levels. The simulative processes corresponding to the activities of the first level are automatic, unconscious and local (Gallese, 2003), whereas the processes of the second level are voluntary, conscious and

multi-component. In an advanced process of mindreading, a selection mechanism is necessary to attribute the hypotheses of possible mental states of the other person; only then the simulation can be executed, therefore simulation at this stage is not automatic or unconscious.

In analogy with simulative process related to other domains, such as perception, motor processes, imagery, and memory, I hypothesize that simulation of mental states is a process that implements different and connected mechanisms, such as anticipation and self sustained inner loops (Alexander, DeLong, & Strick, 1986). Mindreading is anticipatory in the sense that it anticipates the execution of an action and generates predictions of all possible consequences of different actions.

In the case of control for movement, for example, the oculomotor system (which has the function to stabilize the visual world on the retina, through automatic reflexes) can be used to simulate movements before their execution (Berthoz, 1996). This simulation allows a comparison of the consequences of the movement of the body without the execution of this movement. The anticipatory/projective process is driven by an inner loop.

We could think that in the process of mindreading the brain simulates the consequences of different possible mental states and chooses according to a “comparer mechanism”. If this hypothesis is true, it should implement circuits such as the basal ganglia-thalamo-cortical loops that are organized in modular loops (Alexander et al., 1986). The presence and the activity of these self-sustained inner loops would give to the brain the opportunity to act as hypotheses generator. Hypotheses are generated through a simulative process, in which the brain simulates actions. These internal circuits enable the brain to engage in endogenous and independent (by external stimuli) activity.

The main point to be retained is that simulative processes are necessary and efficient. In complex cognitive situations (e.g. catch a ball, drive at high speed, etc.) and in complex social situations (e.g. detect other’s intentions or beliefs), the brain does not solve complicated differential equations nor does it find the game theoretical equilibrium (Nash, 1950) of the interaction; instead, it activates an internal simulative process that compares the consequences of the possible actions. Through this process, the brain selects and executes an action.

During the simulative process, the brain “matches and simplifies the external configuration with an internally predetermined or acquired repertoire of sensory or motor patterns”, the internal model of the limb in the example of catching a ball (Berthoz, 1996). The idea that the brain internalizes the property of the effectors systems has been formulated by Bernstein (1967). This internal representation is used during motion, perception and also during cognitive processes like reasoning. This evidence of internal representation is confirmed by results on mental rotation of visual object during comparison tasks (Kosslyn, 1980); and by the temporal similarity in imagined and executed actions (Decety, Jeannerod,

& Prablanc 1989; Sirigu et al., 1995). In the visual task, the results show the correlation between the rotation angle and the solution timing, which indicates the presence of an internal representation.

An analogous simulative process is hypothesized here for the mindreading activity. Thus, the brain internalizes the characteristics of the target and simulates its own decision making process to predict and understand the target's intention and behavior.

This characterization of the simulation process underlying the second level of mindreading is consistent with the simulation theory of theory of mind, which states that “the pretend state used by the interpreter in order to understand the behavior of the target is the result of a deliberate and voluntary act on the side of the interpreter” (Gordon, 1986; Goldman, 1989).

People predict and interpret the behavior of others by imagining being in their situation (in terms of their mental state). Individuals simulate other individuals' behavior on the basis of their own motives and social predisposition, through a process of introspection, in the sense that “we use ourselves as a model for the person we are describing or predicting” (Stich & Nichols, 1995). People “put themselves in the other's shoes,” in the sense that they project themselves into the other's situation without any attempt to project themselves into the other's mind (Gordon, 1995). Simulation theory states that we predict and explain the behavior of other individuals by a simulative process, i.e. we simulate the decision-making process of the other individual by using part of our cognitive systems “off-line” (Goldman, 1995; Gordon, 1995). “The simulation approach postulates that the heuristics or material employed in mentalizing make essential use of the attributer's own psychology. In the standard lore of simulation theory, an attributer who wishes to predict a target's decision begins by creating pretend states in himself that correspond (or so he thinks) to prior states of the target. He feels these pretend states into his own decision-making mechanism, and sees what decision the mechanism outputs.” (cf. Goldman, 2001, p. 2).

During the progression from the first to the second level of mindreading, the frontal areas assume a fundamental role for non-automatic features of the mechanisms of mindreading, as described above. Prefrontal areas are needed for the activation, control and selective inhibition (Jeannerod, Arbib, Rizzolatti, & Sakata, 1995; Jeannerod, 2001) of the simulative process. Therefore, frontal areas are necessary for voluntariness (second level).

4. Summary and concluding remarks

In this paper, I claimed that action and emotion recognition represent the basis of a more sophisticated mindreading mechanism. These first components allow the individual to construct the self-other representation, which is a prerequisite of mindreading. The mirror neurons solve the problem of

interpersonal relationship, integrating the self with the other in a single neural system, thus creating an interpersonal link (Gallese, 2003; Jeannerod, 2003). The distinction between the two levels presented here is due to their different underlying simulation mechanisms. In the first level, simulation is automatic, unconscious and preconceptual; while in the second level simulation is voluntary and conceptual. The presence of two levels is consistent with extensive evidence of the discontinuity in the developmental process related to mindreading (Baron-Cohen, 1995; Frith & Frith, 2003). Indeed, as described in Frith and Frith (2003), implicit mentalizing (first level) is present around the age of 18 months, while more sophisticated and explicit mentalizing process arises approximately during the fourth year of age (second level). I explain this discontinuity with the nature of the two different simulation processes and their requirement in terms of brain structure's development. Thus, the simulation process underlying the second level requires a higher development of frontal areas of the brain.

In the second level of mindreading we simulate the mental states of the other individuals using our own decision-making mechanism. This process is domain specific, considering that our decision-making mechanisms are different and specialized for different contexts. Degrees of knowledge of the others and the context (Coricelli, McCabe, & Smith, 2000), ranging from certainty to uncertainty; and the different levels of recursive reasoning (depths of reasoning), in terms of thinking about the others thinking about us thinking about them and so on, are crucial factors in the definition of the brain circuits that are needed to solve the interactive situation. This approach is in contrast with the existence of a single theory-of-mind module, and calls for future studies aimed at understanding the underlying complexity of the mechanisms that drive social interaction.

Acknowledgements

This work, and in particular the idea of “two levels of mindreading”, as described here, is the result of many conversations about theory of mind with Alvin Goldman and Vittorio Gallese during my permanence in Tucson, Arizona. I am also extremely grateful to Mark Jeannerod for having accepted me in the *Institut des Sciences Cognitives* in Lyon, believing that people with very different background might contribute to the development of cognitive science. This work was supported by *Action Concertee Incitative (System Complexes en Sciences Humaines et Sociales)* from CNRS.

References

- Adolphs, R., Tranel, D., Damasio, H., & Damasio, A. R. (1994). Impaired recognition of emotion in facial expressions following bilateral damage to the human amygdala. *Nature*, 372, 669–672.
- Adolphs, R., Tranel, D., & Damasio, A. R. (1998). The human amygdala in social judgment. *Nature*, 393, 470–474.

- Adolphs, R., Tranel, D., & Baron-Cohen, S. (2002). Amygdala damage impairs recognition of social emotions from facial expressions. *Journal of Cognitive Neuroscience*, *14*, 1–11.
- Alexander, G. E., DeLong, M. R., & Strick, P. L. (1986). Parallel organization of functionally segregated circuits linking basal ganglia and cortex. *Annual Review Neuroscience*, *9*, 357–381.
- Allison, T., Puce, A., & McCarthy, G. (2000). Social perception from visual cues: Role of the STS region. *Trends Cognitive Science*, *4*, 267–278.
- Baron-Cohen, S. (1995). *Mindblindness: An essay on autism and theory of mind*. Cambridge, MA: MIT Press.
- Baron-Cohen, S., Ring, H., Wheelwright, S., Bullmore, E., Brammer, M., Simmons, A., et al. (1999). Social intelligence in the normal and autistic brain: An fMRI study. *European Journal of Neuroscience*, *11*, 1891–1898.
- Bernstein, N. A. (1967). *The coordination and regulation of movement*. New York: Pergamon Press.
- Berthoz, A. (1996). Neural basis of decision in perception and in the control of movement. In A. R. Damasio, et al. (Eds.), *Neurobiology of decision-making*. Springer-Verlag.
- Blakemore, S. J., & Decety, J. (2001). From the perception of action to the understanding of intention. *Nature Reviews*, *2*, 561–567.
- Blakemore, S. J., Fonlupt, P., Pachot-Clouard, M., Darmon, C., Boyer, P., Meltzoff, A. N., et al. (2001). How the brain perceives causality: An event related fMRI study. *NeuroReport*, *16*, 3737–3744.
- Bonda, E., Petrides, M., Ostry, D., & Evans, A. (1996). Specific involvement of human parietal systems and the amygdala in the perception of biological motion. *The Journal of Neuroscience*, *16*, 3737–3744.
- Brothers, L., & Ring, B. (1992). A neuroethological framework for the representation of minds. *Journal of Cognitive Neuroscience*, *4*, 107–118.
- Calder, A. J., Lawrence, D., Keane, J., Scott, S. K., Owen, A. M., Christoffels, I., et al. (2002). Reading the mind from eye gaze. *Neuropsychologia*, *40*, 1129–1138.
- Calvert, G. A., Bullmore, E. T., Brammer, M. J., Campbell, R., Williams, S. C. R., McGuire, P. K., et al. (1997). Activation of auditory cortex during silent lip reading. *Science*, *276*, 593–596.
- Carr, L., Iacoboni, M., Dubeau, M. C., Mazziotta, J. C., & Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: A relay from neural system for imitation to limbic areas. *Proceeding of National Academy of Science U.S.A.*, *100*, 5497–5502.
- Castelli, F., Happe, F., Frith, U., & Frith, C. (2000). Movement and mind: A functional imaging study of perceptions and interpretation of complex intentional movement patterns. *NeuroImage*, *12*, 314–325.
- Coricelli, G., McCabe, K., & Smith, V. (2000). Theory-of-mind mechanism in personal exchange. In Hatano, et al. (Eds.), *Affective minds* (pp. 249–259). Elsevier Science.
- Decety, J., & Grezes, J. (1999). Neural mechanisms subserving the perception of human actions. *Trends Cognitive Science*, *3*, 172–178.
- Decety, J., Jeannerod, M., & Prablanc, C. (1989). The timing of mentally represented actions. *Behavioral Brain Research*, *34*, 35–42.
- di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: A neurophysiological study. *Experimental Brain Research*, *91*, 176–180.
- Fadiga, L., Fogassi, L., Pavesi, G., & Rizzolatti, G. (1995). Motor facilitation during action observation: A magnetic stimulation study. *Journal of Neurophysiology*, *73*, 2608–2611.
- Farroni, T., Csibra, G., Simion, F., & Johnson, M. H. (2002). Eye contact detection in humans from birth. *Proceeding of National Academy of Science U.S.A.*, *99*, 9602–9605.
- Fox, R., & McDaniel, D. (1982). The perception of biological motion by human infants. *Science*, *218*, 486–487.
- Frith, U., & Frith, C. D. (2003). Development and neurophysiology of mentalizing. *Philosophical Transactions of the Royal Society of London: Biological Sciences*, *358*, 459–473.
- Gallagher, H. L., & Frith, C. D. (2003). Functional imaging of theory of mind. *Trends in Cognitive Sciences*, *7*, 77–83.
- Gallese, V. (2003). The manifold nature of interpersonal relations: The quest for a common mechanism. *Philosophical Transaction: Biological Sciences*, *358*, 517–528.
- Gallese, V., & Goldman, A. (1998). Mirror neurons and the simulation theory of mind-reading. *Trends in Cognitive Sciences*, *2*, 493–501.
- Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain*, *119*, 593–609.
- Goldman, A. (1989). Interpretation psychologized. *Mind and Language*, *4*, 161–185.
- Goldman, A. (1995). Interpretation Psychologized? In M. Davies & T. Stone (Eds.), *Folk psychology: The theory of mind debate*. Oxford: Blackwell.
- Goldman, A. (2001). *Using your mind to read others*. University of Arizona Working Paper.
- Gordon, R. M. (1986). Folk psychology as simulation. *Mind and Language*, *1*, 158–171.
- Gordon, R. M. (1995). Folk psychology as simulation? In M. Davies, T. Stone, & Folk (Eds.), *Psychology: The theory of mind debate*. Oxford: Blackwell.
- Grafton, S. T., Arbib, M. A., Fadiga, L., & Rizzolatti, G. (1996). Localization of grasp representations in humans by positron emission tomography: 2 Observation compared with imagination. *Brain Research*, *112*, 103–111.
- Grezes, J., Costes, N., & Decety, J. (1998). Top down effect of strategy on the perception of human biological motion. *Cognitive Neuropsychology*, *15*, 553–582.
- Grezes, J., Fonlupt, P., Bertenthal, B., Delon-Martin, C., Segebarth, C., & Decety, J. (2001). Does perception of biological motion rely on specific brain regions? *NeuroImage*, *13*, 775–785.
- Grossman, E. D., & Blake, R. (2002). Brain areas active during visual perception of biological motion. *Neuron*, *35*, 1167–1176.
- Hainline, L. (1978). Developmental changes in visual scanning of face and non-face patterns by infants. *Journal of Experimental Child Psychology*, *25*, 90–115.
- Hains, S. M., & Muir, D. W. (1940-195). Infant sensitivity to adult eye direction. *Child Development*, *67*.
- Haith, M., Bergman, T., & Moore, M. (1977). Eye contact and face scanning in early infancy. *Science*, *198*, 855–865.
- Iacoboni, M., Woods, R. P., Brass, M., Bekkering, H., Mazziotta, J. C., & Rizzolatti, G. (1999). Cortical mechanisms of human imitation. *Science*, *286*, 2526–2528.
- Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage*, *14*, 103–109.
- Jeannerod, M. (2003). The mechanism of self-recognition in humans. *Behavioral Brain Research*, *142*, 1–15.
- Jeannerod, M., Arbib, M. A., Rizzolatti, G., & Sakata, H. (1995). Grasping objects: The cortical mechanisms of visuomotor transformation. *Trends Neuroscience*, *18*, 314–320.
- Johansson, G. (1973). Visual perception of biological motion and a model of its analysis. *Perception and Psychophysics*, *14*, 202–211.
- Kosslyn, S. M. (1980). *Image and mind*. Cambridge, Mass: Harvard University Press.
- Maurer, D. (1985). Infants' perception of facedness. In T. Field & N. Fox (Eds.), *Social perception in infants* (pp. 73–100). Norwood, NJ: Ablex.
- Maurer, D. (1993). Neonatal synaesthesia: Implication for the processing of speech and faces. In B. De Boysson-Bardies, et al. (Eds.), *Developmental neurocognition: Speech and face processing in the first year of life*. Kluwer.
- Meltzoff, A. N., & Decety, J. (2003). What imitation tells us about social cognition: A rapprochement between developmental psychology and cognitive neuroscience. *Philosophical Transaction of the Royal Society of London B*, *358*, 491–500.
- Meltzoff, A. N., & Moore, M. K. (1977). Imitation of facial and manual gestures by human neonates. *Science*, *198*, 75–78.

- Meltzoff, A. N., & Moore, M. K. (1983). Newborn infants imitate adult facial gestures. *Children Development*, 54, 702–709.
- Meltzoff, A. N., & Moore, M. K. (1989). Imitation in newborn infants: Exploring the range of gestures imitated and the underlying mechanisms. *Developmental Psychology*, 25, 954–962.
- Nash, J. F. (1950). Equilibrium points in n-Person Games. *Proceedings of the National Academy of Sciences*, 36, 48–49.
- Nichols, K., & Champness, B. (1971). Eye gaze and the GSR. *Journal of Experimental Social Psychology*, 7, 623–626.
- Pavlova, M., Lutzenberger, W., Sokolov, A., & Birbaumer, N. (2004). Dissociable cortical processing of recognizable and non-recognizable biological movement: Analyzing Gamma MEG Activity. *Cerebral Cortex*, 14, 181–188.
- Pelphrey, K. A., Mitchell, T. V., McKeown, M. J., Goldstein, J., Allison, T., & McCarthy, G. (2003). Brain activity evoked by the perception of human walking: Controlling for meaningful coherent motion. *The Journal of Neuroscience*, 23, 6819–6825.
- Puce, A., Allison, T., Bentin, S., Gore, J. C., & McCarthy, G. (1998). Temporal cortex activation in humans viewing eye and mouth movements. *Journal of Neuroscience*, 18, 2188–2199.
- Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research*, 3, 131–141.
- Rizzolatti, G., Fadiga, L., Matelli, M., Bettinardi, V., Perani, D., & Fazio, F. (1996). Localization of grasp representations in humans by PET: Observation versus execution. *Experimental Brain Research*, 111, 246–252.
- Rizzolatti, G., Fadiga, L., Fogassi, L., & Gallese, V. (1999). Resonance behaviors and mirror neurons. *Archives Italiennes Biologie*, 137, 85–100.
- Schaffer, H. (1977). Early interactive development. In H. Schaffer (Ed.), *Studies in mother-infant interaction*. Academic Press.
- Shaw, P., Lawrence, E. J., Radbourne, C., Bramham, J., Polkey, C. E., & David, A. S. (2004). The impact of early and late damage to the human amygdala on theory of mind reasoning. *Brain*, 127, 1535–1548.
- Sirigu, A., Cohen, L., Duhamel, J. R., Pillon, B., Dubois, B., Agid, Y., et al. (1995). Congruent unilateral impairments for real and imagined hand movements. *NeuroReport*, 6, 997–1001.
- Stern, D. (1977). *The First Relationship: Infant and Mother*. Cambridge, MA: Harvard University Press.
- Stern, D. (1985). *The interpersonal world of the infant*. Basic Books.
- Stich, S., & Nichols, S. (1995). Folk psychology: Simulation or tacit theory? In M. Davies & T. Stone (Eds.), *Folk psychology: The theory of mind debate*. Oxford: Blackwell.
- Stone, V. E., Baron-Cohen, S., Calder, A., Keane, J., & Young, A. (2003). Acquired theory of mind impairments in individuals with bilateral amygdala lesions. *Neuropsychologia*, 41, 209–220.
- Vaina, L. M., Solomon, J., Chowdhury, S., Sinha, P., & Belliveau, J. W. (2001). Functional neuroanatomy of biological motion perception in humans. *Proceeding National Academy of Science U.S.A.*, 98, 11656–11661.
- Wolff, P. (1963). Observations on the early development of smiling. In B. Foss (Ed.), *Determinants of Infant Behavior*. New York: Wiley.