ψυχη PSYCHE

Motor Intentions versus Social Intentions: One System or Multiple Systems?

Pierno, Ansuini, and Castiello
Department of General Psychology
University of Padua
Via Venezia, 8
35131 Padova
Italy
Andrea Cristiano Pierno
Caterina Ansuini
(c) Umberto Castiello
andreacristiano.pierno@unipd.it
caterina.ansuini@unipd.it
umberto.castiello@unipd.it

PSYCHE 13/2, April 2007

KEY WORDS: fMRI, Gaze direction, Grasping, Humans, Mirror neurons, Monkeys, Social cognition, Superior temporal sulcus.

COMMENTARY ON: P. Jacob & M. Jeannerod. (2003). *Ways of Seeing: The Scope and Limits of Visual Cognition.* Oxford: Oxford University Press, + 287pp. ISBN 0198509200.

ABSTRACT: In this fine book philosopher Pierre Jacob and well-known cognitive neuroscientist Marc Jeannerod collaborate to bring together many key findings in the visual ventral ('what') and dorsal ('where' and 'how') systems. One of Jacob and Jeannerod's major contribution is to highlight the mechanisms that allow for skilful social interactions. They propose a distinction between the 'mirror neuron' system for perceiving and responding to object-oriented actions and a 'social perception network' devoted to the visual analysis of human actions directed towards conspecifics. In this review we will discuss some recent neurophysiological, neuropsychological and brain imaging studies suggesting that this dichotomy might be too strict.

1. Introduction

A key question for psychologists concerns the mechanisms that allow for skilful social interactions. Although enormous advances in our understanding of the links between the mind, the brain, and behaviour have been made in the last few decades, these have been largely based on studies in which people have been considered as strictly isolated units.

For example, studies might typically examine the kinematics of volunteers performing a reaching and grasping action towards an object (e.g., Jeannerod, 1981) without the intention of using that object to interact with other people.

However, we spend much more of our time performing actions in the context of social interactions. Thus, one of the major functions of our brain must be to plan and execute such actions. The challenge then is to understand whether a specific 'social' action pattern exists and whether such actions can be differentiated from those directed towards inanimate objects.

In this book Jacob and Jeannerod tackle this important challenge by investigating the mechanisms that underlie the enactment of different types of social interactions. They pull together the recently discovered 'mirror cell' evidence and various 'social system' findings in ways that show the strong wired-in linkage between perception-for-action and action.

The perception of non-social intentional action by others involves, among other things, so-called 'mirror' cells in the ventral-premotor area of monkeys, discovered in the early 1990s. Mirror cells are sensori-motor cells that fire both when observing *others* make what seems to be an intentional action toward an object, and when one makes the *same* action toward that object. This circuit seems to transform object-specific information into motor plans for responding to those objects.

Parallel to the non-social 'mirror system', a 'social perception' system including the superior temporal sulcus (STS), the amygdala and the orbito-frontal cortex, processes emotionally-rich facial expressions, bodily posture and actions of others, and triggers appropriate emotional responses in oneself. Thus it detects other persons' assumed *social* motor intentions, triggers automatic social/emotional response plans in oneself, and so facilitates automatic intentional responses. The output from both the mirror and social perception systems serve as visual input to the mind-reading/Theory of Mind system, which our authors only briefly touch on.

To put it simply, Jacob and Jeannerod propose that the mirror system detects motor intentions, i.e. intentions directed towards inanimate objects, and may not be sufficient for the understanding of social intentions. In contrast, the social perception system detects social intentions, i.e. intentions to affect a conspecific's behaviour. There are, however, different ways to understand this distinction. For instance, one may argue that motor intentions are part of the process of the understanding of social intentions. Alternatively it might be said that the understanding of social intentions not only requires the understanding of motor intentions, but it is sometimes the same thing. The crucial issue is that a valid conceptual distinction between both kinds of intentions has yet to be provided. Do they share the same neural basis? Or the same mechanisms?

2. Evidence for a unified system in social perception

Recent neurophysiological, neuroimaging and neuropsychological findings converge on the idea of a unified system specialised for the coding of both social and non-social intentions. In other words, a system that is not only sensitive to the reading of intentions when actions are directed towards inanimate objects, but also to the reading of intentions when actions are directed towards an object with the (implicit) intent to affect a conspecific's behaviour. Thus, with the intent of some forms of social interaction.

2.1. Neurophysiological evidence

Recent neurophysiological studies focusing on the mirror system seem to suggest that this system may also be involved in the reading of other individuals' motor intention. For example, the sight of a graspable object and possibly the intention to act upon it, elicits the same neural activation within the ventral premotor cortex as is evoked by the execution of the corresponding grasping actions (Fadiga et al., 2000). Neurons within the inferior parietal lobe seem to be responsible for reading the motor intentions of others (Fogassi et al., 2005). Furthermore neurons within the STS respond selectively to hand movements but also to the direction of gaze, and play a role in signalling the direction of another individual's attention to objects (Jellema et al., 2000). Thus, on the basis of the above considerations, it is physiologically plausible that all these areas may be simultaneously involved in the coding of motor and/or social intentions. Of course recording from single cells within one brain area at a time prevents the possibility to detect simultaneous action observation related activity in other brain regions. Therefore, if other areas involved in the processing of the social significance of bodily movements respond during the observation of an object-oriented action, their activity would have been undetected.

Evidence towards the concept that the 'mirror system' may be part of a more comprehensive system dedicated to observing and understanding the actions of others may be found in the electrophysiological work conducted on primates. Keysers and Perrett (2004) describe a neural network in the primate brain which appears to be implicated in the capacity to understand the actions of others. This network, named by the authors as the 'action observation system', is comprised of three main cortical areas: the premotor cortex (F5), the inferior parietal lobule (PF), and the STS which in turn strongly projects to the amygdala and to the orbitofrontal cortex. Remember that the latter three areas are the core areas of the 'social' network hypothesised by Jabob and Jeannerod.

Whereas in both the inferior parietal cortex and the premotor area F5 (inferior frontal gyrus in humans, BA44) there are neurons responding both to the sight and the execution of grasping or other hand–object interactions (i.e. mirror neurons), the cerebral cortex in and near the STS is activated by the observation but not by the execution of movements of the eyes and hands, and more generally by the observation of biological movements (Oram and Perrett, 1994). Therefore, based on the anatomical connections between these areas and on their functional properties it has been proposed that this system can learn to match the observed actions with the monkey's own actions and to discriminate the monkey's own actions from the actions of others.

2.2. Neuroimaging evidence

As the 'mirror' system appears to exist also in humans (Rizzolatti et al., 2001; Allison et al., 2000; Puce and Perrett, 2003) it may be advanced that these brain structures can provide a plausible framework for understanding human social perception, that is for the analysis of actual or implied bodily movements and the related cues (e.g. gaze direction) that provide socially relevant information. Hence, in light of the above reported neurophysiological evidence it may be argued that the dichotomy proposed by Jacob and Jannerod between a 'mirror system' and a 'social perception system' may be too strict in that both systems may be involved in the processing of motor and social aspects concerned with the observation and the understanding of other people actions. In this connection recent neuroimaging evidence suggests that the action observation system may be entirely involved in the analysis of social aspects of action. The context in which the action occurs and the gaze pattern associated with both the execution of an action and the intention to act may play a pivotal role in ascribing social meaning to an observed action. Indeed, the majority of the neuroimaging studies aimed at considering the neural basis of action observation confined their investigations to situations in which action observation activations were triggered by the view of a grasping hand detached from other body parts. Thus, little attention was given to situations in which other body parts such as face and eyes were visible. This might explain why these studies described the mirror system as being mainly involved in the processing of motor but not social intentions. In other words, studies aimed at investigating mirror-type activations often showed only an isolated arm/hand ensemble performing a reaching action, showing neither the context in which the action takes place nor other parts of the model, e.g. face, gaze direction (e.g., Buccino et al., 2001). This may account for the Jacob and Jeannerod proposal to restrict the involvement of the mirror system to the reading of motor rather than social intentions.

In a recent study Iacoboni et al. (2005) asked participants to observe three types of stimuli: grasping hand actions without a context, context only (scenes containing objects), and grasping hand actions performed in two different contexts. In the latter condition the context suggested the different intention associated with the grasping action (either drinking or cleaning). Actions embedded in contexts elicited asignificant signal increase in the right inferior frontal gyrus and the adjacent sector of the ventral premotor cortex where hand actions are represented. Thus, two components of the mirror system, previously thought to be involved only in action recognition, were also involved in understanding the intentions of others. These findings suggest that the mirror system responds differently with respect to the type of context in which a given action takes place and plays a role in coding the motor intention of an actor performing a given grasping act. Although these actions are not explicitly directed towards a conspecific, the meaning of such actions and the different motor intentions (grasping for drinking or grasping for cleaning) that can be inferred from the observed actions may affect a conspecific's behaviour by causing a new mental state or representation in the observer's brain. In this respect, it may be argued that in such an experimental situation the intention to grasp an inanimate object carries a social component that, according to Jacob and Jeannerod's proposed dichotomy, should be coded solely by the'social perception network'.

To date, previous studies gave little attention to action observation type of activations that are triggered not only by a moving hand but also by the presence of a cue which has been proposed to be fundamental for the understanding of others' executed or intended behaviour. That is, the perception and interpretation of eye gaze (Allison et al., 2000; Pelphrey et al., 2003; Saxe et al., 2004; Wheaton et al., 2004). Noticeably, paying attention to other people's gaze activates an important component of the action observation system, the STS, which in turn is reciprocally connected to the amygdala, a brain structure involved in gaze monitoring. Thus, the question of whether attention to gaze modulates the action observation system with particular reference to intentional states is still under debate and an untested question.

In this respect a recent neuroimaging study conducted in our laboratory (Pierno et al., in press), investigated the role played by gaze in understanding the intentions associated with the actions of others. To address this issue we made use of one of the most well-established neural markers of action understanding: fMRI responses of the action observation system (e.g. Buccino et al., 2001). The strong response to the observation of grasping actions in a network of areas including the precentral gyrus, the inferior parietal lobule, the inferior frontal gyrus and the STS has been replicated in a number of neuroimaging studies (Buccino et al., 2001; Decety et al., 1997; Decety and Grezes, 1999; Rizzolatti et al., 1996; Tai et al., 2004). We aimed at inducing activation within the action observation system on the basis of gaze coding without showing overt hand actions. This strategy provides a critical test for the distinction between a mirror system and a social perception system, because a strong engagement of the mirror system when observing a model only gazing towards an object would argue against this system being engaged only for the recognition of object-oriented actions and motor intentions. This is because inferring motor intentions from gaze does not only involve the capacity to understand other people's intentions to perform object-oriented actions, but necessarily requires a certain degree of social intelligence. That is, the ability to intentionally cause (from a model's perspective) and read (from an observer's perspective) mental states in the mind of a conspecific and to attribute mental states to him/her.

Participants observed three different types of movie all representing a human actor seated at a table, on top of which an object was positioned. In the first movie the human actor reached towards and grasped the target object (grasping condition). In the second movie the human actor gazed at the target object without performing any grasping action (gaze condition). In the third movie the human actor remained still and maintained the eyes fixed and forward in the presence of the target object (control condition). The grasping and the gaze conditions were pitted against the control condition. In both 'grasping' and 'gaze' conditions bilateral activation within the precentral gyrus, the inferior frontal gyrus, the inferior parietal lobule, and STS was detected, thus arguing in favour of the hypothesis that the action observation system can be triggered by gaze and is involved in perceiving social intentions. In other words, signalling with gaze the presence of an object activates in an observer a neural response similar to that elicited by the observation of a reach-to-grasp action. This signifies that the action observation system is involved in the coding of both motor and social intentions.

An important aspect of the present results is that whereas previous studies have proposed a specific role for the inferior frontal gyrus in the coding of intentions behind observed actions (Iacoboni et al., 2005), we have revealed involvement of the entire action-observation system (Keyser and Perrett, 2004). The interconnected activations of STS, the inferior frontal gyrus, the precentral gyrus and the inferior parietal lobe that we have reported for the gaze condition could indicate that these areas are all important when intentions have to be inferred, at least from gaze.

2.3. Neuropsychological evidence

Further evidence supporting the notion of a general unified system for the processing of both motor and social aspects of actions comes from recent work conducted by means of different techniques on autism. Autism is a pervasive developmental disorder associated with a unique profile of aberrant social behaviour and characterised by deficits in social and communicative skills (Baron-Cohen, 1995). In particular children with autistic features seem to be blind to the mental significance of another person's gaze and show an abnormal coding of another's gaze. Whereas normal children do use gaze-direction as a cue for reading mental states such as desires and goals, children with autism fail to use eye-direction to infer mental states.

As our fMRI study indicated, the entire action observation system seems to be involved in both the understanding of overt actions and in the reading of intentions from other people's gaze (Pierno et al., in press). Therefore, it may be hypothesized that the difficulties experienced by autistic children in using gaze information to read others' mental sates are due to an abnormal functioning of this system.

Following this logic, behavioural evidence conducted on autistic children from our laboratory nicely fits with the hypothesis that failure to read and infer other people intentions from gaze may be highly correlated to dysfunctions within the action observation system. Along the lines of the previously described fMRI experiments, we designed a kinematic experiment aimed at assessing whether children with autism have a disadvantage in the coding of gaze direction which prevents them from understanding the actions of others (Pierno et al., 2006). Previous evidence demonstrated that kinematic analysis allows one to examine the facilitation effects on action following the observation of a model performing an overt action towards an object or simply gazing towards the very same object (Castiello, 2003; Castiello et al., 2002; Edwards et al., 2003). For instance, observing a model performing a reach to grasp movement facilitates the same action performed by an observer immediately after upon the same object. Importantly, similar facilitation effects are evident in the observer's kinematics following the observation of a model simply gazing towards the same object. In contrast, when the observers are prevented from using information about the model's gaze, facilitation effects are not evident.

In our kinematic study normal and autistic subjects observed a model either grasping or simply observing an object (grasping and gaze conditions respectively). Subsequently the participants were requested to perform a grasping action towards the same object. These two conditions were compared with a control condition in which the participants grasped the object after having observed the model standing behind the object performing neither a grasping nor a gazing action.

Our core finding was that in contrast to normal children, children with autism did not show any type of motor facilitation following the observation of either a grasping or a gazing action towards an object. Further, normal children did not show any facilitation effect when the model gazed away from the object. The interesting suggestion here is that normal subjects can infer from the model's gaze how the model would act upon that object. In turn this possible inference about the model's motor intentions would prime the observers' motor system producing facilitation effects in their own subsequent movement. In other words, by simulating the other person's motor processes in one's own mind the same processes should re-activate when one executes the same action themselves. In light of the above mentioned neuroimaging work (Pierno et al., in press) in which the process of understanding other people intentions from gaze activates the brain structures of the action observation system, these behavioural findings suggest that the lack of motor facilitation found in autistic children may be attributed to dysfunctions within this system.

Along these lines, recent EEG evidence reported that at the basis of the autistic abnormal social behaviour there are consistent neurobiological impairments within the mirror system (Oberman et al., 2005). In this study 'mu' wave suppression over sensorimotor cortex—a marker of mirror neuron activity—was measured while participants (autistic and control subjects) observed both their own actual movements and movements performed by others. The results indicated that autistic subjects showed mu wave suppression only to self-performed movements but not to the same movements performed by others suggesting consistent impairments within the mirror neuron system. In addition, recent fMRI investigations in autistic people have reported bilateral anatomical abnormalities localized in the STS and in 'mirror' areas (Pelphrey et al., 2004; Waiter et al., 2004; William et al., 2001).

All together these findings provide anatomical and neurophysiological evidence suggesting that the entire action observation system is dysfunctional in autistic people and may explain why in the above mentioned kinematic study we did not find facilitation effects for both the gaze and the action conditions for the autistic group. For the 'action' condition abnormal activation of mirror areas may have not allowed a proper matching between the observed action and the subsequent to-be-performed action. In turn this would have prevented the beneficial effects of action priming. For the 'gaze' condition, the abnormal activation of the mirror system, in terms of intentional coding, together with abnormal activation of the STS area, which is necessary for gaze coding, would have prevented the coding of motor intention from gaze.

3. Conclusions

'Ways of Seeing' by Jacob and Jannerod is one of the most complete and well-balanced books in the field of cognitive sciences to have appeared in the last ten years. The book mainly focuses on visual perception, which has been addressed exploiting the most powerful tools in psychophysics, neurophysiology, epistemology and conceptual analysis nowadays available. Its main point is that the processing of visual information is more complex and articulated than suggested by previous theories (Marr, 1982; Milner and Goodale, 1995). In short, this insightful book reshapes our knowledge on how the brain processes visual information to understand the external world and to act in both social and non-social fashions upon it.

Our review focused on the last part of the book, which, by widening the horizon of our "ways of seeing", addresses an issue that has been gaining importance in the last decade: the perception of social action in humans. The discovery of mirror neurons adds a new level to the perception of social action, however, Jacob and Jeannerod suggest that their presence cannot ensure the recovery of others' social intentions. In other words, they propose that the 'mirror system' may serve the detection of motor intentions, i.e. intentions directed towards inanimate objects. In contrast, a separate system, namely the 'social perception system' is recruited for the detection of social intentions, i.e. intentions to affect a conspecific's behaviour. However, as explained above this distinction leads to the debate of whether the mirror system suffices or not for intentions understanding. Jacob and Jeannerod seem to suggest that the latter is the case. However, on the basis of recent neuroimaging, neurophysiological, and behavioural evidence we propose that this distinction is still to be fully ascertained.

We are inclined to suggest a more unified approach to the understanding of social action. First, one may argue against a clear-cut distinction between motor and social intentions in that motor intentions can often carry social aspects, especially when they are communicated through gaze. Second, in our view the notion of two distinct systems for the understanding of social and non-social intentions could be revised according to recent findings hereby reported. Converging evidence seems to suggest that the human brain may have a complex neural circuit, comprised of the mirror system and 'social' areas such as the superior temporal sulcus and the amygdala, which is responsible for the highest social perception ability, that is, the ability to attribute mental states to others, an obviously highly adaptive function.

References

Allison, T., Puce, A., & McCarthy, G. (2000). Social perception from visual cues: role of the STS region. *Trends in Cognitive Sciences, 4,* 267-278.

Baron-Cohen, S. (1995). *Mindblindness*. Cambridge: MIT Press.

Buccino, G., Binkofski, F., Fink, G. R., Fadiga, L., Fogassi, L., Gallese, V., Seitz, R. J., Zilles, K., Rizzolatti, G., & Freund, H. J. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: an fMRI study. *European Jouranl of Neuroscience. 13,* 400-404.

Castiello U (2003). Understanding other people's actions: intention and attention. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 416-430.

Castiello, U., Lusher, D., Mari, M., Edwards, M.G., & Humphreys, G.W. (2002). Observing a human or a robotic hand grasping an object: Differential motor priming effects. In W. Prinz and B. Hommel (Eds.), *Common mechanisms in perception and action: Attention and Performance XIX* (pp. 315-333). New York: Oxford University Press.

Decety, J., & Grezes, J. (1999). Neural mechanisms subserving perception of human actions. *Trends in Cognitive Sciences, 3,* 172-178.

Decety, J., Grezes, J., Costes, N., Perani, D., Jeannerod, M., Procyk, E., Grassi, F., & Fazio, F. (1997). Brain activity during observation of actions. Influence of action content and subject's strategy. *Brain 120,* 1763-1777.

Edwards, M.G., Humphreys, G.W., & Castiello U. (2003). Motor facilitation following action observation: A behavioural study in prehensile action. *Brain and Cognition, 53,* 495-502.

Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (2000). Visuomotor neurons: ambiguity of the discharge or 'motor' perception. *International Journal of Psychophysiology, 35*, 165-177.

Fogassi, L., Ferrari, P. F., Gesierich, B., Rozzi, S., Chersi, F., & Rizzolatti, G. (2005). Parietal lobe: From action organization to intention understanding. *Science, 308*, 662-667.

Iacoboni, M., Molnar-Szakacs, I., Gallese, M., Buccino, G., Mazziotta, J. C., & Rizzolatti, G. (2005). Graping the intentions of others with one's own mirror neuron system. *PloS Biology. 3: e79,* 0529-0535.

Jellema, T., Baker, C. I., Wicker, B., and Perrett, D. I. (2000). Neural Representation for the Perception of the Intentionality of Actions. *Brain and Cognition, 44*, 280-302.

Jeannerod, M. (1981). Intersegmental coordination during reaching at natural visual objects. In J. Long & A. Baddeley (Eds.), *Attention and Performance IX* (pp. 153-169). Hillsdale, NJ: Erlbaum.

Keysers, C.,& Perrett, D. I. (2004). Demystifying social cognition: a Hebbian perspective. *Trends in Cognitive Sciences, 8*, 501-507.

Marr, D. (1982). *Vision*. San Francisco: W. H. Freeman

Milner D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford: Oxford University Press.

Oberman, L. M., Hubbard, E. M., McCleery, J. P., Altshuler, E. L., Ramachandran, V. S., & Pineda, J. A. (2005). EEG evidence for mirror neuron dysfunction in autism spectrum disorders. *Cognitive Brain Research, 24,* 190-198.

Oram, M. W., & Perrett, D. I. (2004). Responses of anterior superior temporal polysensory neurons (Stpa) to biological motion stimuli. *Journal of Cognitive Neuroscience. 6,* 109-129.

Pelphrey, K. A., Singerman, J. D., Allison,T., & McCarthy, G. (2003). Brain activation evoked by the perception of gaze shifts: the influence of context. *Neuropsychologia, 41,* 156–170.

Pierno, A. C., Becchio, C., Wall, M. B., Smith, A. T., & Castiello U. (in press). When gaze turns into grasp. *Journal of Cognitive Neuroscience*.

Pierno, A. C., Mari, M., Georgiou, I., Glover, S., & Castiello, U. (2006). Failure to read motor intentions from gaze in children with autism. *Neuropsychologia, 44,* 1483-1488.

Puce, A., & Perrett, D. I. (2003). Elctrophysiology and brain imaging of biological motion. *Philosophical Transactions of the Royal Society of London Series B, Biological Science. 358,* 435-445.

Rizzolatti, G., Fadiga, L., Matelli, M., Bettinardi, V., Paulesu, E., Perani, D., & Fazio, G. (1996). Localization of grasping representations in humans by PET. 1. Observation versus Execution. *Experimental Brain Research, 111*, 246-252.

Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience, 2,* 661-670.

Saxe, R., D. –K. Xiao, Kovacs, D. L., Perrett, D. I., & Kanwisher, N. (2004). A region of right posterior superior temporal sulcus responds to the observed intentional actions. *Neuropsychologia, 42,* 1435-1446.

Tai, Y. F., Scherfler, C., Brooks, D. J., Sawamoto, N., & Castiello, U. (2004). The human premotor cortex is mirror only for biological actions. *Current Biology, 14,* 117-120.

Waiter, G. D., Williams, J. H. G., Murray, A. D., Gilchrist, A. Perrett, D. I. & Whiten, A. (2005). A voxel-based investigation of brain structure in male adolescents with autistic spectrum disorder. *Neuroimaage*, *24,* 619-625.

Wheaton, K. J., Thompson, J. C., Syngeniotis, A., Abbott, D. F.,& Puce, A. (2004). Viewing the motion of human body parts activates different regions of premotor, temporal, and parietal cortex. *NeuroImage, 22,* 277-288.

William, J. H. G., Whiten, A., Suddendorf, T. & Perrett, D. I. (2001). Imitation, mirror neurons, and autism. *Neuroscience Biobehavioural. Reviews*, *25,* 287-295.