

## Giacomo Rizzolatti - selected references

- 1 Rizzolatti, G., Semi, A. A., & Fabbri-Destro, M. (2014). Linking psychoanalysis with neuroscience: the concept of ego. *Neuropsychologia*, 55, 143-148.  
Notes: Through his whole life Marc Jeannerod was fascinated by Freud's thinking. His interest in Freud is witnessed by several of his writings in which he expresses interest in building a bridge between psychoanalysis and cognitive neuroscience. Following Jeannerod's ideas we discuss here a fundamental point of Freud's construction, the concept of ego, from a neurophysiological point of view. We maintain that, in order both to act coherently and to have a basic, first person, understanding of the behavior of others, it is necessary to posit the existence of a neurophysiological "motor" ego similar to the "rider" of the Freudian metaphor. We review then a series of neurophysiological findings showing that the systems underlying the organization of action and conscious perception are both mediated by a cortical motor network formed by parieto-frontal circuits. In conclusion, we show that the activity of this network has strong similarities to that postulated by Freud for the conscious part of ego. We also propose that the default-mode network might represent that part of ego that is mostly involved in unconscious processes
- 2 Di, C. G., Di, D. C., Rochat, M. J., Sinigaglia, C., Bruschweiler-Stern, N., Stern, D. N. et al. (2014). The neural correlates of 'vitality form' recognition: an fMRI study. *Social Cognitive and Affective Neuroscience*, 9, 951-960.  
Notes: The observation of goal-directed actions performed by another individual allows one to understand what that individual is doing and why he/she is doing it. Important information about others' behaviour is also carried out by the dynamics of the observed action. Action dynamics characterize the 'vitality form' of an action describing the cognitive and affective relation between the performing agent and the action recipient. Here, using the fMRI technique, we assessed the neural correlates of vitality form recognition presenting participants with videos showing two actors executing actions with different vitality forms: energetic and gentle. The participants viewed the actions in two tasks. In one task (what), they had to focus on the goal of the presented action; in the other task (how), they had to focus on the vitality form. For both tasks, activations were found in the action observation/execution circuit. Most interestingly, the contrast how vs what revealed activation in right dorso-central insula, highlighting the involvement, in the recognition of vitality form, of an anatomical region connecting somatosensory areas with the medial temporal region and, in particular, with the hippocampus. This somatosensory-insular-limbic circuit could underlie the observers' capacity to understand the vitality forms conveyed by the observed action
- 3 Rochat, M. J., Veroni, V., Bruschweiler-Stern, N., Pieraccini, C., Bonnet-Brihault, F., Barthelemy, C. et al. (2013). Impaired vitality form

recognition in autism. *Neuropsychologia*, 51, 1918-1924.

Notes: Along with the understanding of the goal of an action ("what" is done) and the intention underlying it ("why" it is done), social interactions largely depend on the appraisal of the action from the dynamics of the movement: "how" it is performed (its "vitality form"). Do individuals with autism, especially children, possess this capacity? Here we show that, unlike typically developing individuals, individuals with autism reveal severe deficits in recognizing vitality forms, and their capacity to appraise them does not improve with age. Deficit in vitality form recognition appears, therefore, to be a newly recognized trait marker of autism

- 4 Rizzolatti, G. & Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. *Nature Reviews Neuroscience*, 11, 264-274.

Notes: The parieto-frontal cortical circuit that is active during action observation is the circuit with mirror properties that has been most extensively studied. Yet, there remains controversy on its role in social cognition and its contribution to understanding the actions and intentions of other individuals. Recent studies in monkeys and humans have shed light on what the parieto-frontal cortical circuit encodes and its possible functional relevance for cognition. We conclude that, although there are several mechanisms through which one can understand the behaviour of other individuals, the parieto-frontal mechanism is the only one that allows an individual to understand the action of others 'from the inside' and gives the observer a first-person grasp of the motor goals and intentions of other individuals  
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- 5 Rizzolatti, G., Fogassi, L., & Gallese, V. (2009). The mirror neuron system: A motor-based mechanism for action and intention understanding. In M.S.Gazzaniga (Ed.), *The cognitive neurosciences* (4 ed., pp. 625-640). Cambridge,MA: MIT Press.

- 6 Rizzolatti, G. & Fabbri-Destro, M. (2008). The mirror system and its role in social cognition. *Current Opinion in Neurobiology*, 18, 179-184.

Notes: Experiments in monkeys have shown that coding the goal of the motor acts is a fundamental property of the cortical motor system. In area F5, goal-coding motor neurons are also activated by observing motor acts done by others (the 'classical' mirror mechanism); in area F2 and area F1, some motor neurons are activated by the mere observation of goal-directed movements of a cursor displayed on a computer screen (a 'mirror-like' mechanism). Experiments in humans and monkeys have shown that the mirror mechanism enables the observer to understand the intention behind an observed motor act, in addition to the goal of it. Growing evidence shows that a deficit in the mirror mechanism underlies some aspects of autism

7 Rizzolatti, G., Fogassi, L., & Gallese, V. (2006). Mirrors of the mind. *Scientific American*, 295, 54-61.

8 Rizzolatti, G., Ferrari, P. F., Rozzi, S., & Fogassi, L. (2006). The inferior parietal lobule: where action becomes perception. *Novartis Foundation Symposium*, 270, 129-140.

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The view defended in this article is that action and perception share the same neural substrate. To substantiate this view, the anatomical and functional organization of the inferior parietal lobule (IPL) is reviewed. In particular, it will be shown that many IPL neurons discharge selectively when the monkey executes a given motor act (e.g. grasping). Most interestingly, most of them fire only if the coded motor act is followed by a subsequent specific motor act (e.g. placing). Some of these action-constrained motor neurons have mirror properties and selectively discharge during the observation of motor acts when these are embedded in a given action (e.g. grasping for eating, but not grasping for placing). Thus, the activation of these IPL neurons allows the observer not only to recognize the observed motor act, but also to predict what will be the next motor act of the action, that is to understand the intentions of the action's agent. The finding that the same neurons that are active during the execution of specific motor acts also mediate the understanding of the 'what' and the 'why' of others' actions provides strong evidence for a common neural substrate for action and perception

9 Rizzolatti, G. & Fadiga, L. (2005). The mirror neuron system and action recognition. In H.-J.Freund, M. Jeannerod, M. Hallett, & R. Leiguarda (Eds.), *Higher-order motor disorders: from neuroanatomy and neurobiology to clinical neurology* (1 ed., pp. 141-157). Oxford: Oxford University Press.

10 Rizzolatti, G. & Buccino, G. (2005). The mirror neuron system and its role in imitation and language. In S.Dehaene, J.-R. Duhamel, M. D. Hauser, & G. Rizzolatti (Eds.), *From monkey brain to human brain* (1 ed., pp. 213-233). Cambridge,MA: MIT Press.

11 Rizzolatti, G. & Craighero, L. (2005). Mirror neuron: a neurological approach to empathy. In J.-P.Changeux, A. R. Damasio, W. Singer, & Y. Christen (Eds.), *Neurobiology of human values* (1 ed., pp. 107-123). Berlin: Springer.

12 Rizzolatti, G. & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience*, 27, 169-192.

A category of stimuli of great importance for primates, humans in particular, is that formed by actions done by other individuals. If we want to survive, we must understand the actions of others. Furthermore, without action understanding, social organization is impossible. In the case of humans, there is another faculty that depends on the observation of others' actions: imitation

learning. Unlike most species, we are able to learn by imitation, and this faculty is at the basis of human culture. In this review we present data on a neurophysiological mechanism--the mirror-neuron mechanism--that appears to play a fundamental role in both action understanding and imitation. We describe first the functional properties of mirror neurons in monkeys. We review next the characteristics of the mirror-neuron system in humans. We stress, in particular, those properties specific to the human mirror-neuron system that might explain the human capacity to learn by imitation. We conclude by discussing the relationship between the mirror-neuron system and language

- 13 Rizzolatti, G., Fogassi, L., & Gallese, V. (2004). Cortical mechanisms subserving object grasping, action understanding, and imitation. In M.S.Gazzaniga (Ed.), *The cognitive neurosciences III* (3 ed., pp. 427-440). Cambridge,MA: MIT Press.

Notes: In this chapter we provide evidence that the cortical motor system, in addition to its role in action organization, is also involved in action understanding and imitation. In the first part of the chapter, we propose, on the basis of the functional properties of a monkey premotor area (area F5), that at the core of the cortical motor system there are vocabularies of motor actions. Neurons forming these vocabularies store both knowledge about actions and the description of how this knowledge has to be applied. When a specific population of these neurons becomes active, an internal representation of a specific action is generated. This action representation may be used for planning and executing goal-directed actions and for recognizing actions made by another individual. Action understanding is based on a match between an observed action and its internal motor representation (mirror system). In the second part of the chapter, we review data showing that a mirror system, similar to that of the monkey, exists also in humans. We present evidence that in humans this system is also involved in imitation

- 14 Rizzolatti, G. (2004). Understanding the actions of others. In N.Kanwisher & J. Duncan (Eds.), *Functional neuroimaging of visual cognition. Attention and performance XX* (1 ed., pp. 3-26). Oxford: Oxford University Press.

Notes: "Association lecture". Rizzolatti's discovery of "mirror neurons" in the monkey premotor cortex - neurons responding either when a particular action is carried out, or when it is observed in the behaviour of another - has led to an explosion of studies addressing the physiological basis for both action imitation and action understanding. A Rizzolatti discusses, these ideas now reach far beyond the context of simple movements like grasping and reaching, informing ideas from social perception to language production

- 15 Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences*, 8, 396-403.

Notes: In this article we provide a unifying neural hypothesis on how

individuals understand the actions and emotions of others. Our main claim is that the fundamental mechanism at the basis of the experiential understanding of others' actions is the activation of the mirror neuron system. A similar mechanism, but involving the activation of visceromotor centers, underlies the experiential understanding of the emotions of others

- 16 Rizzolatti, G., Fogassi, L., & Gallese, V. (2000). Cortical mechanisms subserving object grasping and action recognition: A new view on the cortical motor functions. In M.S. Gazzaniga (Ed.), *The new cognitive neurosciences* (2 ed., pp. 539-552). Cambridge, MA: MIT Press.

Notes: This chapter provides evidence for a new and broader view of the functions of the cortical motor system. On the basis of the functional properties of a monkey premotor area (area F5), the authors propose that at the core of the cortical motor systems there are vocabularies of motor actions. Neurons forming these vocabularies store knowledge about actions and the description of how this knowledge must be applied. When a specific population of these neurons becomes active, an internal copy of a specific action is generated. This copy may be used for two purposes: (1) planning and executing goal-directed actions or (2) recognizing actions made another individual. The action recognition is based on a match between an observed action and its internal motor copy. Finally, evidence is reviewed showing that an action observation/execution matching system, similar to that of the monkey, also is present in humans

- 17 Rizzolatti, G. & Arbib, M. A. (1998). Language within our grasp. *Trends in Neurosciences*, 21, 188-194.

Notes: Istituto di Fisiologia Umana, Università di Parma, Italy ; ABSTRACT: In monkeys, the rostral part of ventral premotor cortex (area F5) contains neurons that discharge, both when the monkey grasps or manipulates objects and when it observes the experimenter making similar actions. These neurons (mirror neurons) appear to represent a system that matches observed events to similar, internally generated actions, and in this way forms a link between the observer and the actor. Transcranial magnetic stimulation and positron emission tomography (PET) experiments suggest that a mirror system for gesture recognition also exists in humans and includes Broca's area. We propose here that such an observation/execution matching system provides a necessary bridge from 'doing' to 'communicating', as the link between actor and observer becomes a link between the sender and the receiver of each message

- 18 Rizzolatti, G., Fogassi, L., & Gallese, V. (1997). Parietal cortex: from sight to action. *Current Opinion in Neurobiology*, 7, 562-567.

Notes: Istituto di Fisiologia Umana, Università di Parma, Via Gramsci 14, 43100, Parma, Italy. Fisioum@Symbolic.Pr.It  
Recent findings have altered radically our thinking about the functional role of the parietal cortex. According to this view, the parietal lobe consists of a

multiplicity of areas with specific connections to the frontal lobe. These areas, together with the frontal areas to which they are connected, mediate distinct sensorimotor transformations related to the control of hand, arm, eye or head movements. Space perception is not unitary, but derives from the joint activity of the fronto-parietal circuits that control actions requiring space computation

- 19 Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain*, 119, 593-609.

Notes: Istituto di Fisiologia Umana, Università di Parma, Italy We recorded electrical activity from 532 neurons in the rostral part of inferior area 6 (area F5) of two macaque monkeys. Previous data had shown that neurons of this area discharge during goal-directed hand and mouth movements. We describe here the properties of a newly discovered set of F5 neurons ('mirror neurons',  $n = 92$ ) all of which became active both when the monkey performed a given action and when it observed a similar action performed by the experimenter. Mirror neurons, in order to be visually triggered, required an interaction between the agent of the action and the object of it. The sight of the agent alone or of the object alone (three-dimensional objects, food) were ineffective. Hand and the mouth were by far the most effective agents. The actions most represented among those activating mirror neurons were grasping, manipulating and placing. In most mirror neurons (92%) there was a clear relation between the visual action they responded to and the motor response they coded. In approximately 30% of mirror neurons the congruence was very strict and the effective observed and executed actions corresponded both in terms of general action (e.g. grasping) and in terms of the way in which that action was executed (e.g. precision grip). We conclude by proposing that mirror neurons form a system for matching observation and execution of motor actions. We discuss the possible role of this system in action recognition and, given the proposed homology between F5 and human Brocca's region, we posit that a matching system, similar to that of mirror neurons exists in humans and could be involved in recognition of actions as well as phonetic gestures 9612