THE MIRROR ROOTS OF SOCIAL COGNITION

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1. Introduction

Different approaches within the cognitive sciences have emphasized the relevance of analyzing the relation between a cognitive system and its environment. In the case of human beings the term 'environment' often indicates social context, as most of our everyday activities are characterized by social interchange. In fact, it might be stressed how human cognitive abilities, or rather generally the ability to think, is built upon social interaction often imbued with an emotional coloring. During social intercourse overt bodily behavior is interpreted as a mark of something as insubstantial as mental activity. Various accounts of how this may occurs are been proposed and an intersubjective understanding is currently the subject of profound speculation.

A central question concerning this problem area is how do we capture the intentional dimension of others' actions. One hypothesis is that in our everyday ascriptions of beliefs, desires, and intentions we do not always need to resort to inferential processes, but may at times rely on a more pragmatic knowledge and an immediate understanding of what others are doing and why they are doing it. This may well be true not only for actions, but also for their emotional coloring. Recent neurophysiological findings have offered new grounding for this type of knowledge by referring to specific neural circuitries called mirror neuron systems. In the following paragraphs we will present some of the most recent studies on this topic.

We will provide an initial description of the mirror neuron system for action both in monkeys and humans by highlighting its functional properties. Then we shall point out the relevance of the emotional coloring which characterizes actions especially in the early phases of development before going on to analyze the existing literature on a mirror neuron system for emotion understanding. Finally, we will consider what happens when social cognition breaks down as in

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cases of autistic spectrum disorders (ASD). References to autism will clarify our understanding of those mechanisms, that underlie the production and recognition of others' actions and emotions, as well as how actions may not always rely on high-level inferential processes, but rather on an ability to directly match the others' observed behavior with our own motor or emotional repertoire.

2. The mirror neuron system for action

Mirror neurons are a distinct class of sensory motor neurons originally recorded in the ventral premotor cortex (area F5) of the macaque brain.[1] The defining property of this class of neurons is that they become active both when a monkey itself is executing a given motor act (e.g. grasping a piece of food), and when it is simply observing the action being performed by another (human or monkey) thus the neurons are 'mirroring' the other's motor behavior. In order to trigger mirror neuron activations an actual interaction between a biological effector (i.e. hand or mouth) and an object is required. The mere sight of an object, of a mimic, or of a non-object-directed motor action does not suffice to activate a response in monkeys.

A comparison between motor acts that were effectively observed and motor acts that were effectively executed showed that most mirror neurons display congruence between their sensory and motor responses. Linked to this parameter of congruence mirror neurons are classified into 'strictly congruent', when the observed and the executed actions correspond both in terms of goals (e.g. grasping) and in the means used to reach them (i.e. grip type), vs. 'broadly congruent'. The latter indicates a conspicuous set of mirror neurons, for which congruence is confined to the goal of the action.

Reference is often made to a *mirror neuron system* and in fact the presence of neurons responding to actions performed by others is not limited to the ventral premotor cortex. Neurons responding to an observation of hand grasping actions are also reported to occur in the superior temporal sulcus (STS), the rostral part of the inferior parietal lobule including the cortex within the intraparietal sulcus, as well as other different sectors of F5.[2] It is well known for some time that STS neurons code biological movements, becoming active when observing walking, head turning, torso bending and arm movements as well as hand-object interactions.[3] Although motor acts coded by STS neurons

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[1] G. Di Pellegrino, L. Fadiga, L. Fogassi, V. Gallese, G. Rizzolatti, *Understanding motor events: a neurophysiological study*, «Experimental Brain Research», 91 (1992), pp. 176-180. V. Gallese, L. Fadiga, L. Fogassi, G. Rizzolatti, *Action recognition in the premotor cortex*, «Brain», 119 (1996), pp. 593-609. G. Rizzolatti, L. Fadiga, V. Gallese, L. Fogassi, *Premotor cortex and the recognition of motor actions,* «Cognitive Brain Research», 3 (1996a), pp. 131-141.

[2] K. Nelissen, G. Luppino, W. Vanduffel, G. Rizzolatti, G.A. Orban, *Observing others: multiple action representation in the frontal lobe*, «Science», 310 (2005), pp. 332-336.

[3] D. I. Perrett, M. H. Harries, R. Bevan, S. Thomas, P. J. Benson, A. J. Mistlin, A. J.

are similar to those coded by F5 neurons, STS coding is exclusively visual. Currently, STS neurons have not demonstrated a possession of motor properties, they are not considered as a part of the mirror system.

A different case may be made for the neurons present in the rostral part of the inferior parietal lobule. These neurons display motor properties, discharging during the execution of specific motor acts, while many of them also respond to somatosensory and visual stimuli. Some of the latter seem to have mirroring properties analogous to the ones we have described for the F5 mirror neurons, especially in relation to motor acts such as grasping, holding, manipulating and bimanual interactions.[4] Therefore, the monkey mirror neuron system can be considered as constituted of two main nodes, the first located in F5 and the second in the rostral part of inferior parietal lobule.

While up to this point we have explicitly referred only to experiments carried out on monkeys, a number of studies relying on electrophysiological and brain imaging techniques supported evidence that also in humans the observations of another's motor acts activates the cortical areas that are involved in motor activity. Several electroencephalography (EEG) studies have shown that the observation of another's actions desynchronizes the EEG activity of the region located around the central sulcus, this also occurs when the action is performed by the observer himself.[5] Similar results were also obtained by using magnetoencephalography (MEG).[6]

Chitty, J. K. Hietaten, J. E. Ortega, *Frameworks of analysis for the neural representation of animate objects and actions,* «Journal of Experimental Biology», 146 (1989), pp. 87-113. T. Jellema, C. I. Baker, M. W. Oram, D.I. Perrett, *Cell populations in the banks of the superior temporal sulcus of the macaque monkey and imitation*, in Meltzoff, A. N. & Prinz, W. (Eds.), *The Imitative Mind: Development, Evolution and Brain Bases*, Cambridge, Cambridge University Press, 2002, pp. 267-290.

[4] L. Fogassi, V. Gallese, L. Fadiga, G. Rizzolatti, *Neurons responding to the sight of goal-directed hand/arm actions in the parietal area PF (7b) of the macaque monkey*, «Society for Neuroscience Abstracts», 24 (1998), pp. 257-259. V. Gallese, L. Fogassi, L. Fadiga, G. Rizzolatti, *Action representation in the inferior parietal lobule*, in W. Prinz, B. Hommel (Eds.), *Attention and Performance*, vol. 19, New York: Oxford University Press, 2002, pp. 247-266. P. F. Ferrari, V. Gallese, G. Rizzolatti, L. Fogassi, *Mirror neurons responding to the observation of ingestive and communicative mouth actions in the monkey ventral premotor cortex,* «European Journal of Neuroscience», 17 (2003), pp. 1703-1714.

[5] S. Cochin, C. Barthelemy, B. Lejeune, S. Roux, J. Martineau, Perception of motion and EEG activity in human adults, «Electroencephalography and Clinical Neurophysiology», 107 (1998), pp. 287-295. S. Cochin, C. Barthelemy, S. Roux, J. Martineau, Observation and execution of movement: similarities demonstrated by quantifed electroencephalograpy, «European Journal of Neuroscience», 11 (1999), pp. 1839-1842. V. S. Ramachandran, L. M. Oberman, *Broken Mirrors. A theory of autism*, «Scientific American», November, 2006. L. M. Oberman, E. M. Hubbard, J. P. McCleery, E. L. Altschuler, J. A. Pineda, V. S. Ramachandran, *EEG evidence for mirror neuron disfunction in autism spectrum disorders,* «Cognitive Brain Research», 24 (2005), pp. 190-198.

[6] R. Hari, N. Forss, S. Avikainen, S. Kirveskari, S. Salenius, G. Rizzolatti, *Activa-*

Another piece of evidence of the mirror properties of the human motor system is provided through transcranial magnetic stimulation (TMS). This non-invasive technique uses a coil emanating a magnetic field, which is held close to the head and induces an electrical current in the motor cortex, this in turn allows the recording of motor evoked potentials (MEPs) in the controlateral muscles. Fadiga et al. (1995) recorded MEPs, elicited by the stimulation of the hand field of the left primary motor cortex, from the right arm and hand muscles of volunteers who were requested to witness an experimenter performing transitive and intransitive hand motor acts.[7] The sight of both kinds of motor acts produced an increase in the recorded MEPs, which selectively involved the muscles the individuals used when executing the observed movements.[8]

While these techniques allowed detecting motor neuron activation in humans during the observation of actions performed by others and therefore mirror-like activity, they provided no precise information on the system's actual anatomical architecture. For this purpose other methods were employed such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). These tests rely upon recordings of variations in blood flow in various cerebral regions during performance and observation of given motor acts. These studies allowed localizing a mirror neuron system for action in humans. Highlighting how the observation of others' actions activates a network which includes the visual occipital and temporal areas together with two cortical regions that have mainly motor functions: the rostral part of the inferior parietal lobule, the lower part of the precentral gyrus, and the posterior part of the inferior frontal gyrus.[9]

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tion of human primary motor cortex during action observation: a neuromagnetic study, «Proceedings of National Academy of Sciences of the United States of America», 95 (1998), pp. 15061-15065.

[7] L. Fadiga, L. Fogassi, G. Pavesi, G. Rizzolatti, *Motor facilitation during action observation: a magnetic stimulation study,* «Journal of Neurophysiology», 73 (1995), pp. 2608-2611.

[8] See also M. Gangitano, F.M. Mottaghy, A. Pascual-Leone, *Phase specific modulation of cortical motor output during movement observation*, «Neuroreport», 12 (2001), pp. 1489-1492. S. Clark, F. Tremblay, D. Ste-Marie, *Differential modulation of corticospinal excitability during observation, mental imagery and imitation of hand actions*, «Neuropsychologia», 42 (2004), pp. 105-112. P. Borroni, M. Montagna, G. Cerri, F. Baldissera, *Cyclic time course of motor excitability modulation during observation of a cyclic hand movement,* «Brain Research», 1065 (2005), pp. 115-124.

[9] G. Rizzolatti, L. Fogassi, M. Matelli, V. Bettinardi, E. Paulesu, D. Perani, F. Fazio, *Localization of grasp representations in humans by PET: 1. Observation versus execution*, «Experimental Brain Research», 111 (1996b), pp. 246-252. S. T. Grafton, M. A. Arbib, L. Fadiga, G. Rizzolatti, *Localization of grasp representations in humans by PET: 2. Observation compared with imagination*, «Experimental Brain Research», 112 (1996), pp. 103-111. J. Grèzes, N. Costes, J. Decety, *Top-down effect of strategy on the perception of human biological motion: a PET investigation*, «Cognitive Neuropsychology», 15 (1998), pp. 553-582. J. Grèzes, J.

If the localization of the mirror system in humans has proven to be very similar to the one discovered in monkeys, some differences were found between the mirror system in humans and monkeys as related to functional properties. The first noticeable difference is that in humans mirror neurons seem to respond also to the sight of non-object-related motor acts as well as to mimicked actions, while in monkeys, as stated above, intransitive acts, i.e. acts not directed towards an object, and mimicked actions do not elicit a response. A second difference is that the human mirror system seems to be tuned also to the timing of the observed motor acts, therefore coding both the goal-directedness of an action and the temporal aspects of individual movements leading to the goal.[10]

3. Mechanism and function: what mirror neurons are for

We have shown how mirror neurons display different amounts of congruence between their visual and motor responses. The congruency is such that it allows us to state that when we are observing an action performed by another, the visual stimulus evokes a potential motor act identical (or very similar) to the one, which would be activated during the actual execution of that same act.

However, how can we explain such a potential motor activity? Why should our cortical motor system become active during the observation of actions performed by others and even more so with such a strong congruence? The foremost and highly convincing hypothesis to date is that this activation is the product of a mechanism that maps the sensory information related to a perceived motor action directly on the kind of motor information which would subtend the eventual execution of that very same motor action and belonging to the observer's motor repertoire. The primary function of such a mapping would be in turn to allow the observer to immediately understand the intentional meaning of the another's action.[11]

Decety, *Functional anatomy of execution, mental simulation, observation and verb generation of actions: a meta-analysis*, «Human Brain Mapping», 12 (2001), pp. 1-19. M. Iacoboni, R.P. Woods, M. Brass, H. Bekkering, J. C. Mazziotta, G. Rizzolatti, *Cortical mechanisms of human imitation*, «Science», (1999), pp. 2526-2528. G. Buccino, F. Binkofski, G. R. Fink, L. Fadiga, L. Fogassi, V. Gallese, R. J. Seitz, K. Zilles, G. Rizzolatti, H.-J. Freund, *Action observation activates premotor and parietal areas in a somatotopic manner: an fMRI study*, «The European Journal of Neuroscience», 13 (2001), pp. 400-404.

[10] See for a review G. Rizzolatti, L. Craighero, *The mirror neuron system*, «Annual Reviews of Neuroscience», 27 (2004), pp. 169-192. See also G. Rizzolatti, M. Fabbri-Destro, *The mirror system and its role in social cognition,* «Current Opinion in Neurobiology» (2008).

[11] See G. Rizzolatti, L. Fogassi, V. Gallese, *Cortical mechanisms subserving object grasping and action recognition: a new view on the cortical motor functions*, in M. S. Gazzaniga, (Ed.), *The Cognitive Neurosciences, Second Edition*. Cambridge, MA, MIT Press (2000), pp. 539-

In order to avoid placing an unnecessary cognitive burden on the above statements, first of all we must first clarify what is meant here by *understanding*, and secondly if this type of understanding may tell us something about the *intentional* meaning of the other person's actions. We might start out by stating that in referring to an understanding of motor events, there is no wish to resort to any form of explicit, reflexive or inferential knowledge that may serve to establish that the seen and executed actions are identical or similar. What is meant here is rather that an ability to immediately recognize a specific action type in an observed 'motor event', differentiates it from another's, and finally uses this information in an appropriate way. This ability is given by the distinctive functional characteristic of mirror neurons of directly mapping an observed motor event onto a potential motor act. The so obtained motor potential act is similar to the one the observer would produce if she were to plan or perform that same action; therefore it is saturated by the same intentional-motor content.

Presence of such content allows stating that mirror neurons have a role in intentional understanding, and evidence supporting this conclusion may be found in a study by Umiltà et al. (2001).[12] In this experiment a monkey initially observed an experimenter grasping an object. In this first condition the entire motor act and the object were fully visible. Then the monkey watched the experimenter while performing the same grasping act, but in this second condition its final part (i.e. the grasping and the object) were hidden from view by a black screen. Single neurons were recorded in the two conditions and results showed that mirror neurons responded to the observation of the hand's grasping even in the second condition, i.e. when the final phase of grasping and the object were hidden from view. This indicates that mirror neurons' direct matching mechanism is able to disambiguate an entire motor act from an observed partial sequence of movements.

Another experiment, carried out by Kohler et al. (2002), supports the hypothesis that this mechanism reflects understanding of intentional meaning of a motor act, and not simply its visual features.[13] In this case mirror neuron activity in F5 was recoded while the monkey was observing either the experimenter performing a noisy motor act (i.e. breaking a peanut) or hearing the its sound without viewing the action. Results indicated that a consistent number of mirror neurons (later termed 'audio-visual mirror neurons') responded

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

[12] M. A. Umiltà, E. Kohler, V. Gallese, L. Fogassi, L. Fadiga, C. Keysers, G. Rizzolatti, *I know what you are doing: a neurophysiological study*, «Neuron», 32 (2001), pp. 91-101.

[13] L. Kohler, C. Keysers, M. A. Umiltà, L. Fogassi, V. Gallese, G. Rizzolatti, *Hearing sounds, understanding actions: action representation in mirror neurons,* «Science», 297 (2002), pp. 847-848.

to these different experimental conditions in a selective and congruent manner. In other words, some mirror neurons responded to peanut breaking both when it was observed and when it was only heard, and when it was both heard and observed, but not when another motor act was seen or heard, nor to non-specific sound presented. This indicates that while sensory information may change, its motor coding stays constant. Visual aspects, according to this experiment may enhance comprehension, but since the motor act may be understood using other elements (e.g. sound), then mirror neurons are coding the motor act even in absence of a visual stimulus.

Mirror neuron activation, according to these studies, is not constrained by the information's wholeness or by its sensory modality, relying rather on the observer's motor repertoire which is at the basis of her own ability for action. This seems to be true not only for hand- and mouth- actions, but also for tool-mediated motor acts, even when they involve opposite sequences of movements. Very recently Umiltà et al. (2008) carried out an experiment with macaque monkeys, which were trained to grasp objects using two types of pliers (i.e. 'normal' and 'reverse'), requiring opposite hand movements.[14] When using the normal pliers, the monkey grasped the object presented to it by opening its paw and then closing it; when using the reverse pliers it first grasped the object by closing its paw and then opening it. All recorded neurons in the F5 area discharged in relation to the goal-related motion of the pliers, maintaining the same relation to the different phases of grasping in both conditions, regardless of the fact that diametrically opposite hand movements were required to achieve that goal. Most strikingly, also F5 mirror neurons were recorded. The motor and visual responses of F5 mirror neurons possessed the same goal-relatedness, that is F5 mirror neurons were able to code the distal goal of the pliers as the same (grasping) both from a motor and from a visual point view, even when the movement of the fingers required to achieve that goal were not only different but diametrically opposite. This finding emphasizes the constitutive role of mirror neuron activation in the action understanding, shedding light on how the ability to visually code the goal of the observed movements and the fineness-of-grain of this goal coding depends upon the observer's motor expertise.

This in line with the evidence from a number of brain-imaging studies carried out during the last few years. Such experiments have shown that activation of the mirror neuron system during action observation is modulated by

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[14] M. A. Umiltà, L. Escola, I. Intskirveli, F. Grammont, M. Rochat, F. Caruana, A. Jezzini, V. Gallese, G. Rizzolatti, *How pliers become fingers in the monkey motor system*, «Proceeding of the National Academic of Sciences of the United States of America», 105 (6) (2008), pp. 2209-2213.

the observer's motor repertoire.[15] As this repertoire develops, diversifies and becomes increasingly sophisticated, the ability to immediately understand the actions of others develops, diversifies, and becomes increasingly sophisticated in parallel as well.

It is, therefore, the observer's motor repertoire, which allows the mirror mechanism to code observed movements in terms of specific motor goals. This is true also in cases in which the observed movements are performed by a robot arm. A study by Gazzola et al. (2007), in fact demonstrated that, notwithstanding evident differences in the shape and kinematics of human and robot arms, observation of movies where either a human or a robot arm grasped objects brought to the activation of the parieto-frontal mirror system.[16] However surprising this also holds in cases in which the observer has no direct experience of the observed act. Gazzola et al. (2007) analyzed two aplasic patients, who are born without arms and hands, during the observation of hand acts. Results indicated that the mirror system of the two aplasic patients became active even during the observation of these acts, recruiting areas involved in the execution of motor acts having the same motor goal but using different effectors (e.g. feet instead of hands).[17]

At this particular point we have only referred to isolated motor acts, but our everyday actions have a more complex structure implying an embedding of individual motor acts in a goal-oriented hierarchy. For example the simple motor act presented above of grasping an object, may be embedded in broader action schemas with different motor intentions, constituted by specific motor goal hierarchies, e.g. grasping-to-eat, grasping-to-place, etc. In this sense the goal-centered coding described above may be part of a more complex coding with different chains of single motor acts.

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[15] G. Buccino, F. Lui, N. Canessa, I. Patteri, G. Lagravinese, F. Benuzzi, C.A. Porro, G. Rizzolatti, *Neural circuits involved in the recognition of actions performed by nonconspecifics: An fMRI study*, «Journal of Cognitive Neuroscience», 16 (2004), pp. 114-126. B. Calvo-Merino, D.E. Glaser, J. Grezes, R.E. Passingham, P. Haggard, *Action observation and acquired motor skills: an fmri study with expert dancers*, «Cerebral Cortex», 15 (2005), pp. 1243-1249. B. Calvo-Merino, J. Grezes, D.E. Glaser, R.E. Passingham, P. Haggard, *Seeing or doing? Influence of visual and motor familiarity in action observation,* «Current Biology», 16 (19), (2006), pp. 1905-1910. B. Haslinger, P. Erhard, E. Altenmuller, U. Scroeder, H. Boecker, A.O. Ceballos-Baumann, *Transmodal sensorimotor networks during action observation in professional pianists*, «Journal of Cognitive Neuroscience», 17 (2006), pp. 282-293.

[16] V. Gazzola, G. Rizzolatti, B. Wicker, C. Keysers, *The anthropomorphic brain: The mirror neuron system responds to human and robotic actions*, «NeuroImage», 35 (2007), pp. 1674-1684.

[17] V. Gazzola, H. van der Worp, T. Mulder, B. Wicker, G. Rizzolatti, C. Keysers, *Aplasics born without hands mirror the goal of hand actions with their feet,* «Current Biology», 17 (14) (2007), pp. 1235-1240.

A study by Fogassi et al. (2005) has looked into this broader picture and observed the activity of parietal mirror neurons during hand grasping aimed at achieving different intentions: in a first condition the monkey grasped a piece of food to eat it, whereas in a second condition the same piece of food was grasped to place it in a container.[18] Neuron recordings showed how grasping neurons selectively discharged in different ways in the two conditions (controls for force, kinematics of reaching movements, and stimulus type indicated that the selectivity was not to be ascribed to these factors).

This selective activation may seem strange, as it appears costly to have grasping neurons, which code for grasping only if this is linked to a specific action types. However, those perplexities are soon to be explained once we take this type-specific coding as evidence towards considering these neurons as elements of pre-formed chains coding for the entire action and therefore allowing for the fluidity of motion, that characterizes both humans and animals.

Even more importantly a similar selectivity emerges during action observation. While observing an experimenter performing the same motor action chain, the monkey's parietal mirror neurons are differentially activated depending on the type of action in which the coded motor act is embedded. Temporal aspects of these responses are also relevant. In fact, the parietal neurons seem to anticipate the intentional meaning of the action by becoming active as soon as the hand (of the monkey or of the experimenter) takes the appropriate shape for a specific motor action both during the execution and during the observation task. This strengthens our previous statement according to which complex motor goal hierarchies, i.e. motor intentions are immediately understood and the final goal is anticipated. This type of knowledge is essential because it can be considered as a valid basis for intentional understanding since it concerns not only the individual motor acts, but also the concatenation of these motor acts into complex motor chains.

A similar mechanism was highlighted in humans. In a fMRI study conducted by Iacoboni et al. (2005) participants were presented with three types of images: the first one depicting a hand grasping a mug in absence of context, the second one showing merely a context (scenes with objects) and finally a third showing the hand grasping the mug within different contexts. These differing contexts were designed so as to indicate that the person was about to have tea ("drinking" context) or that the person had just finished having tea ("clearing away" context).[19] Hand actions embedded in specific contexts, com-

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[18] L. Fogassi, P.F. Ferrari, B. Gesierich, S. Rozzi, F. Chersi, G. Rizzolatti, *Parietal lobe: from action organization to intention understanding*, «Science», 308 (2005), pp. 662-667.

[19] M. Iacoboni, I. Molnar-Szakacs, V. Gallese, G. Buccino, J.C. Mazziotta, G. Rizzolatti, *Grasping the intentions of others with one's own mirror neuron system*, «Plos Biology», 3 (2005), pp. 529-535.

pared with the other two conditions, yielded a significant signal increase in the caudal part of the inferior frontal gyrus, a region containing the frontal node of the human mirror neuron system. This suggests that this system is able not only to encode single motor acts, but also to code the general motor intention with which the single motor acts are performed (e.g. grasping-for-drinking or grasping-for-tidying-away).

More recently Cattaneo et al. (2007) have shown, albeit indirectly, that motor intention understanding in humans is based upon a motor chain organization similar to that found in monkeys.[20] In this EMG experiment participants were children and they were asked within one condition to either grasp a piece of food to eat it or to place it in a container while in another condition they simply observed an experimenter doing the same actions (also in this case controls for force, kinematics of reaching movements, and stimulus type were considered). During the execution and observation conditions of both actions the activity of the mouth-opening mylohyoid muscle (MH) of the children was recorded using EMG surface electrodes. Both the execution and the observation of the eating action produced a marked increase of MH activity in children as early as the reaching phase, whereas no MH activity was recorded in the execution and observation conditions of the placing action.

In summary, the discovery of the mirror neuron system for action and its anatomical architecture both in monkeys and humans has called for a revision of our view of the main functions of frontal and parietal motor areas of the brain. The presence of a mirroring activity has raised new questions and proposed some possible answers to our ability to understand others' actions and intention ascription. Obviously mirror neuron system may not be considered as the only means by which we come to understand others' behavior. During our everyday ascriptions of beliefs, desires, expectations and intentions with others different neural mechanisms may well be involved, especially in complex or unusual contexts that require inferential processes.[21] It is however important to stress how the mirror neuron mechanism seems able to capture the intentional dimension of actions, which is common to agent and observer, relying on a vocabulary of acts which enables a type of direct matching and an immediate understanding of what others are doing and of why they are doing what are doing without resorting to any high-level cognitive abilities.

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[20] L. CATTANEO, M. FABRI-DESTRO, S. BORIA, C. PIERACCINI, A. MONTI, G. COSSU, G. RIZZOLATTI, *Impairment of actions chains in autism and its possible role in intention understanding*, «Proceeding of the National Academic of Sciences of the United States of America», 104 (45) (2007), pp. 17825-17830.

[21] M. BRASS, R. M. SCHMITT, S. SPENGLER, G. GERGELY, *Investigating action understanding: inferential processes versus action simulation,* «Current Biology», 17 (2007), pp. 2117-2121. J. M. KILNER, C. D. FRITH, *Action observation: inferring intentions without mirror neurons*, «Current Biology», 18 (2008), pp. 32-33.

4. Sharing emotions

The abovementioned studies have focused on pure motor actions, a further step may be to highlight how motor behaviors possess an emotional coloring which is in turn coded, employing a similar circuitry to the one just described. An individual's action by incorporating an emotional gloss such as a threat or an opportunity, being repulsive or attractive by provoking fear or wonder, disgust or interest, pain or pleasure and so on, often provokes a response, which in turn will possess emotional significance. Emotions are to be understood as manifest in bodily movements, contrary to sentiments, which are considered mainly as a private experience.[22] Within this view, emotions are not an independent behavioral outcome, as much as a component of behavior, imbuing sentient action.

Producing and recognizing emotional states has great social relevance, first of all from a developmental point of view. Various studies highlight in fact how emotional understanding emerges at an early stage of development, and is an essential ingredient in establishing early primary forms of social interaction. Interrelation between baby and caregiver develops through specific patterns, which may be individuated as early as 10 to 12 weeks after birth.[23]

Among these patterns is a specific ability reflecting a baby's tendency to orient their self while engaged in the observation of an object or an event, so as to share this perceptual experience with another individual.[24] This ability termed 'joint attention' is an essential grounding of later emerging social skills, and may take different forms during various developmental stages.[25] For example, Trevarthen and Hubley (1978) analyze the ongoing dynamical and adaptive infant-mother relation by describing the passage from elementary dyadic forms of interactions with persons or objects, which are already present around one or two months of age (called 'primary intersubjectivity'), to new forms of inter-subjectivity in which communicative and praxic modes of action are combined and a more sophisticated system of joint attention is built (termed 'secondary-intersubjectivity').[26] Around nine months of age, the infant combines the physical, privately-known reality near her, with the

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[22] A. R. Damasio, *Looking for Spinoza: Joy, Sorrow and the Feeling Brain,* New York: Harcourt 2003.

[23] M. Cole, S.R. Cole, C. Lightfoot, *The Development of Children*, (fifth edition), New York, Worth Publishers 2005.

[24] P. Mundy, *Joint attention, social-emotional approach in children with autism,* «Developmental Psychopathology», 7 (1995), pp. 63-82.

[25] M. Tomasello, *Joint attention as social cognition*, in Moore, C. & Dunham, P. (Eds.) *Joint attention: Its origins and role in development*. NJ, Hillsdale, Erlbaum, (1995), pp. 103-130.

[26] C. Trevarthen, P. Hubley, *Secondary Intersubjectivity: Confidence, Confiding and Acts of Meaning in the First Year,* in Lock, A. (Ed.) *Action, Gesture and Symbol: The Emergence of Language*, Academic Press, London, 1978, p. 182.

acts of communication towards others, thereby gaining a stronger connection with the caregiver by sharing experience of events and objects.[27] At this stage the infant mustn't be understood as able to ascribe complex mental states to others, but rather fit to establish an emotional engagement with the other's manifest attitudes.[28]

Evidence to the fact that secondary-intersubjectivity relies on emotional engagement may come from underscoring the it is at this same stage that developmental psychologists set the beginning of a new emotionally changed bond between infant and caregiver referred to as 'attachment'.[29] Even if babies display traces of attunement to their caregiver's emotional state earlier in life[30] it is around the age of nine months that babies display specific patterns of emotional attachment seeking their primary caregivers, showing distress if separated from them, being happy when they are reunited with the person they are attached to and finally orienting their actions towards the other even when this is momentarily absent.[31] Elementary mechanisms leading towards the emergence of secondary inter-subjectivity all seem to display specific emotional coloring developing dynamically through cycles of feedback.

These studies all indicate the importance of emotional attunement during the early phases of life by focusing on patterns of emotional production and recognition. As we have highlighted above in the case of action understanding, mirror neuron circuitry is able to link production and recognition, but can a similar case be made for emotions? Can we hypothesize the existence of mirror mechanisms linking the type of emotional production and recognition that was just described as being essential towards the development of later emerging social interactions?

Indirect evidence seems to point out that experiencing and perceiving in others an emotion such as disgust relies on a common neural substrate and that involvement of the insula is fundamental in both cases. This evidence suggests that emotional understanding in the case of disgust does not require any inferential process. Not only brain imaging as well as electro-stimulation

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[27] *Ibidem*, p. 184.

[28] P. J. Hobson, *The cradle of thought*, Oxford, Oxford University Press 2002.

P. J. Hobson, *Autism and Emotion* in F. R. Volkmar, R. Paul, A. Klein, D. Cohen (Eds.) *Handbook of autism and pervasive developmental disorders*, John Wiley & Sons, inc., New Jersey, 2005, pp. 406-425.

[29] J. Cassidy, P. R. Shaver, (Eds.) *Handbook of attachment*, New York: Guilford Press 1999. H. Steele, *Attachment and human development*, «Attachment and Human Development», 5 (1) (2003), p. 1.

[30] T. Field, R. Woodson, R. Greenberg, D. Cohen, *Discrimination and imitation of facial expressions by neonates*, «Science», 218 (1982), pp. 179-181. D. N. Stern, *The interpersonal world of the infant*, New York, 1985.

[31] E. E. Maccoby, *Social development: Psychological growth and the parent-child relationship*, New York: Harcourt Brace Jovanovich 1980.

studies seem to indicate that the anterior part of the insula responds selectively to the sight of facial expressions of disgust,[32] but also clinical data seems to point in the same direction.

Calder et al. (2000) reports the case of a patient (NK) with severe damage to the left insula and surrounding areas in consequence of cerebral haemorrage who displayed an incapacity to recognize disgust in others both visually and acoustically. Other emotions seemed to have been spared by the accident, while following this polimodal deficit NK seemed to be impaired also in his personal experience, as he held to be able to perceive only vague feelings of disgust.[33] Adolphs et al. (2003) describes a somehow similar case of a patient (B) with extensive bilateral lesions to the insula. B was not only unable to recognize disgust in others both relying on visual and auditory stimuli, but did not show any sign of being disgusted himself by eating things that proved totally inedible and disgusting to others.[34]

Neither NK nor B had brain damage restricted to the insula, so a possible argument against such evidence could be raised by hypothesizing that disgust recognition may involve extra-insular areas. A study by Kipps et al. (2007) on patients with Huntington Disease (HD) seems however to disconfirm such an hypothesis bringing further support to a specific involvement of the insula in disgust recognition.[35] HD is a genetic neurological disorder, due to trinucleotide repeat expansion which increases the rate of neuron cell death in selected areas of the brain affecting their functions. While initially ascribed to a basal ganglia dysfunction, recent neuroimaging studies have demonstrated an involvement of the left insula.[36] Kipps et al. (2007) used a statistical imaging tech-

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[32] M.L. Phillips, A.W. Young, C. Senior, M. Brammer, C. Andrei, A.J. Calder, E.T. Bullmore, D.I. Perrett, D. Rowland, S. C. William et al., *A specific neural substrate for perceiving facial expressions of disgust*, «Nature», 389 (1997), pp. 495-498. M. L. Phillips, A. W. Young, S. K. Scott, A. J. Calder, C. Andrew, V. Giampietro, S. C. William, E. T. Bullmore, M. Brammer, J. A. Gray, *Neural responses to facial and vocal expressions of fear and disgust,* «Proceedings of the Royal Society of London Series B Biological Sciences», 265 (1998), pp. 1089-1817. P. Krolak-Salmon, M. A. Henaff, J. Isnard, C. Tallon-Baudry, M. Guenot, A. Vighetto, O. Bertrand, F. Mauguire, *An attention modulated response to disgust in human ventral anterior insula,* «Annals of Neurology», 53 (2003), pp. 446-456.

[33] A. J. Calder, J. Keane, F. Manes, N. Antoun, A. W. Young, *Impaired recognition and experience of disgust following brain injury*, «Nature Neuroscience», 3 (2000), pp. 1077-1078.

[34] R. Adolphs, *Cognitive neuroscience of human social behavior*, «Nature Reviews Neuroscience», 4 (2003), pp. 165-178.

[35] C. M. Kipps, A. J. Duggins, E. A. McCusker, A. J. Calder, *Disgust and Happiness Recognition Correlate with Anteroventral Insula and Amygdala Volume Respectively in Preclinical Huntington's Disease*, «Journal of Cognitive Neuroscience», 19 (7) (2007), pp. 1206-1217.

[36] Phillips et al. 1997, 1998. R. Sprengelmeyer, M. Rausch, U. T. Eysel, H. Przuntek, *Neural structures associated with recognition of facial expressions of basic emotions*, «Proceedings of Royal Society of London Series B Biological Sciences», 265 (1998), pp. 1927-1931.

nique on a group of seventeen preclinical HD participants who had undergone predictive genetic testing and carried the HD gene mutation and seventeen non-positive controls.[37] The study showed positive correlation between volume of the insula and disgust recognition, were participants with the greatest atrophy were most impaired. No correlation between insula volumes and the recognition of other emotions was found.

These cases seem to support the hypothesis of a common neurological structure underlying both recognition and production of disgust, but more direct evidence is needed to uphold the presence of a mirror mechanism and to guarantee that the same region of the insula is active in both conditions.

A study by Wicker et al. (2003) has provided direct evidence to this point.[38] In this study fourteen healthy subjects participated to an fMRI experiment made up of two sessions. In the first session they were exposed to both disgusting and pleasant odors, while in the second section they were asked to observe others exposed to such odors and watching their reactions of pleasure, disgust or indifference. During the first session the olfactory stimuli of disgusting smells caused an activation of the anterior region of the right and left insula, while pleasant smells activated a posterior site in the right insula only. Interestingly, during the second, visual, session the mere sight of expressions of disgust produced insula activation. However, the most interesting finding was that this activation coincided in the anterior part of the left insula to the one seen during the participants' direct experience of disgusting smells. Such evidence allows us to consider mirror-like activity of the type described above, as present in the insula. This fMRI study is particularly relevant as it highlights how abilities to produce and recognize disgust in others, both seem to rely on a common neural substrate mainly involving the left part of the insula.

Sensory information seems to be coded, according to the available data, directly in emotional terms and this appears to be valid also for another primary emotion such as pain.[39] To this point it is interesting to mention a study by Singer et al. (2004) conducted on couples, in order to assess neurological basis of experiencing pain in ourselves or in a loved partner.[40] During this study brain activity of the female partner was measured while painful electric stim-

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[37] Kipps et al. 2007.

[38] B. Wicker, C. Keysers, J. Plailly, J. P. Rovet, V. Gallese, G. Rizzolatti, *Both of us disgusted in my insula: the common neural basis of seeing and feeling disgust*, «Neuron», 40 (2003), pp. 655-664.

[39] W. D. Hutchinson, K. D. Davis, A. M. Lozano, R. R. Tasker, J. O. Dostrovsky, *Pain related neurons in the human cingulate cortex*, «Nature Neuroscience», 2 (1999), pp. 403-405.

[40] T. Singer, B. Seymur, J. O'Doherty, H. Kaube, R.J. Dolan, C.D. Frith, *Empathy for pain involves the affective but not the sensory component of pain*, «Science», 303 (2004), pp. 1157-1162.

ulation was applied to her own hand or to her partner's hand. Results indicated that specific pain-related brain areas become active both when experiencing direct pain and when observing a loved partner while he is experiencing a painful experience. The activation of these affective pain circuits also seems to covary with the subjects' scores on empathy questionnaires, showing that higher scores corresponded to higher activation patterns.

Other studies indicate that it is not strictly necessary for the observed 'object' to be known or familiar in order for it to trigger similar empathic responses.[41] Nevertheless the magnitude of the activation is modulated by affective links to the 'other'.[42] Perceptual, somatovisceral and motor bodily states are therefore relevant in re-experiencing the manifestation of emotional states in others, and this may in turn be essential to an understanding of emotional states.[43]

The discovery of such mirror properties has allowed a better understanding of emotion comprehension and a correct recognition of the direct matching mechanism, which underpins them. In his (2003) book Damasio claimed that seeing pain or disgust in another's face produces a modification in the activation of the observer's corporeal maps, so that the other's emotion is perceived 'as if' one's own.[44] He allowed for an 'as if' circuitry which describes the activation of mirror neuron circuitry in the premotor cortex during observation of the other's facial emotional expressions, which in turn sends copy of activation patterns to the insula, activating the same areas which are active during emotional expression.

The studies mentioned above show that there is no need for such pleonastic mechanism involving the premotor cortex, since the same phenomena can be explained by supposing a mirror mechanism coding the observed facial emotional expressions of others in the corresponding emotive mode directly in the insula. Emotional coloring understanding turns out to be based on our possessing of vocabulary of visceromotor responses that underlies the producing of our emotions as well as the recognizing of the other's emotions, just as a vocabulary of motor acts has been proven to underpin our ability to act as well as to ascribe intentional meaning to other's actions.[45]

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[41] P.L. Jackson, A.N. Meltzoff, J. Decety, How do we perceive the pain of others. A window into the neural processes involved in empathy, Neuroimage, 24 (2005), pp. 771-779. I. Morrison, D. Lloyd, G. di Pellegrino, N. Roberts, *Vicarious responses to pain in anterior cingulate cortex: is empathy a multisensory issue?*, «Cognitive Affective Behavioural and Neuroscience», 4 (2004), pp. 270-278.

[42] T. Singer, B. Seymour, J. P. O'Doherty, K. E. Stephan, R. J. Dolan, C. D. Frith, C. D., *Empathic neural responses are modulated by the perceived fairness of others*, «Nature», 439 (2006), pp. 466-469.

[43] P. M. Niedenthal, *Embodying Emotion*, «Science», 316 (2007).

[44] A. Damasio 2003.

[45] For more details on this point see G. Rizzolatti, C. Sinigaglia, *Mirrors in the brain*, Oxford: Oxford University Press 2008, in particular chap. 7.

5. Breaking down of social cognition

The fact that production and recognition of actions and emotions are closely linked and that this connection underlies primary forms of social cognition and comprehension is confirmed by those deficits, such as autistic spectrum disorders (ASD), which are characterized by a lack of social interchange.

Understanding of ASD is far from having reached a conclusive point, but most authors agree in recognizing that this deficit affects an individual's ability to interact socially in an effective way. Children with autism often do not attempt to make eye contact, display indifference towards others, are one-sided in social interactions, using the other as a tool to indicate a certain need or talking incessantly about one topic and using parrot words. They do not play with peers nor display forms of pretend play, through they join in other's activity only under direct guidance and prefer sameness to novelty, they may perform certain tasks well if they do not involve social understanding.[46]

Traditional approaches to understanding ASD have often described this deficit as characterized by an inability to ascribe mental states to others, stressing the failure of children with ASD in tests that require the ascription of false beliefs.[47] These theoretical perspectives tend to rely on the existence of inner representations, often referring to high-level abilities, which enable to manipulate them. Within this view the failure of children with ASD to interact socially in an effective way is explained as due to a deficit in specific mental modules dedicated to social cognition and specifically to the high-level cognitive ability of ascribing mental states to ourselves and others in order to predict our/their behavioral outcomes.

Recently some authors have proposed to invert this causal chain, reversing the etiological order and considering a deficit in belief ascription as the result of more primary problems in social interaction.[48] This proposal, stemming from a phenomenological observation of everyday social interactions during the first months of life, holds that problems in what we have referred above as forms of 'primary social interactions', may be at the basis of later deficits in the type of meta-cognitive systems which were the main focus of traditional approaches. This distinction has nothing to do with the conscious/uncon-

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[46] U. Kraft, *Detecting autism early*, «Scientific American Mind», vol. 17, n. 5, 2006, October/November.

[47] S. Baron-Cohen, A. Leslie, U. Frith, *Does the autistic child have a 'theory of mind'?*, «Cognition», 21 (1985), pp. 37-46. H. Wimmer, J. Perner, *Beliefs about beliefs. Representation and constraining function of wrong beliefs in young children's understanding of deception*, «Cognition», 13 (1983), pp. 103-112.

[48] S. Gallagher, *The practice of mind: Theory, simulation, or primary interaction*, «Journal of Consciousness Studies», 8 (2001), pp. 83-108.

scious distinction. The meta-cognitive systems that allow for a more theoretical understanding of others' behavior may well be considered unconscious and still result unnecessarily in many of our everyday social practices. It is not the existence of these meta-cognitive structures which is under scrutiny, but rather their role in embodied, on-going social interactions.

Gallagher, following such inverted causation, proposes a theory termed 'interaction theory';[49] other forms of a similar approach have also been called 'Social Orienting model'.[50] These approaches highlight the importance of a closer observation of those mechanisms that regulate primary social interactions by bringing them to centre stage. The hypothesis is that a closer inspection of such mechanisms may bring to light recurrent and definite patterns, which in turn may be disrupted, in autistic spectrum disorders, in a specific way.

The functional properties of mirror neurons and their role in action and emotion understanding seem to pinpoint a specific mechanism which plays a relevant role in primary social interaction and is impaired in ASD. In fact, relevant evidence suggests that one of the mechanisms underlying primary social interactions, which is impaired is the direct matching mechanism described above.

It is worth noting that the relevance of motor disorders in ASD has been downplayed for decades, owing to the major relevance given to meta-cognitive or higher level functions and the lack of an appropriate theoretical framework. Therefore, the mechanisms underlying such motor impairments received little or no attention and remained mostly obscure. However, recent studies promise to shed new light on motor impairments in ASD. According to these studies motor abilities in children with ASD may also rely on strategies that differ from the ones observed in typical development. For example children with ASD seem to rely on feed-back, rather than feed-forward information in their modes of control. Such motor impairment prevents children with ASD from adopting anticipatory postural adjustments.[51]

Different techniques are employed to assess a possible dysfunction in the mirror circuitry involved in action understanding. Oberman et al. (2005) hold that individuals with ASD lack a proper understanding of motor actions performed by others due to a mirror neuron dysfunction. In their study they employed EEG and referred to the suppression of *mu* waves frequency over

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[49] S. GALLAGHER, *Understanding interpersonal problems in autism: Interaction theory as an alternative to theory of mind*, «Philosophy, Psychiatry, and Psychology», 11 (3) (2004), pp. 199-217.

[50] P. MUNDY, J. MARKUS, *On the nature of communication and language impairment in autism*, in SHORE, C.M. (Ed) *The many faces of childhood*, «Pearson Education», (2004), pp. 54-65. L. SPARACI, *Embodying gestures. The social orienting model and the study of early gestures in autism,* «Phenomenology and the Cognitive Sciences», 7 (2) (2008), pp. 203-223.

[51] C. SCHMITZ, J. MARTINEAU, C. BARTHÉLEMY, C. ASSAIANTE, *Motor control and children with autism: deficit of anticipatory function?*, «Neuroscience Letter», 348 (2003), pp. 17-20.

the sensory-motor cortex in healthy controls during action observation and the lack thereof in children with ASD.[52] On a similar note Theoret et al. (2005) using TMS instead revealed how individuals with ASD display a lack of TMS-induced hand muscle facilitation during the observation of motor acts.[53]

Starting from the motor domain other studies have focused on motor mimicry and imitation. An existing detailed review by Rogers and Pennington (1991) has highlighted the presence of an imitation deficit in ASD, considered also by some authors as a possible candidate towards later emerging social impairments.[54] Studies by Williams et al. (2001, 2004) linked the ASD deficit in imitation abilities to a malfunctioning of the mirror neuron system.[55]

It must be said that some studies have recently challenged this view either arguing against a general imitation impairment and a global mirror neuron system deficit in children with ASD[56] or claiming that specific impairments in imitation skills should not be imputed to a malfunctioning mirror neuron system.[57]

Clarifying how and to what extent these studies may represent a true challenge to the relevance of motor deficits and the subsequent impairment in the mirror neuron system for imitation in subjects with ASD is beyond the scopes

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[52] L. M. Oberman, E. H, Hubbard, J. P. McCleery, E. Altschuler, V. S. Ramachandran, J. A. Pineda, *EEG evidence for mirror neuron dysfunction in autism spectrum disorders*, «Cognitive Brain Research», 24 (2005), pp. 190-198.

[53] H. Theoret, E. Halligan, M. Kobayashi, F. Fregni, H. Tager-Flusberg, A. Pascual-Leone, *Impaired motor facilitation during action observation in individuals with autism spectrum disorder*, «Current Biology», 15 (2005), pp. 84-85.

[54] S. J. Rogers, B. A. Pennington, A theoretical approach to the deficits in infantile autism, «Developmental Psychopathology», 3 (1991), pp. 137-162. S. J. Rogers, S. Hepburn, E. Wehner, *Parent reports of sensory symptoms in toddlers with autism and those with other developmental disorders*, «Journal of Autism and Developmental Disorders», 33 (2003), pp. 631-642.

[55] J. H. G. Williams, A. Whiten, T. Suddendorf, D. I. Perrett, *Imitation mirror neurons and autism,* «Neuroscience and Behavioral Reviews», 25 (2001), pp. 287-295. J. H. Williams, A. Whiten, T. Singh, *A systematic review of action imitation in autistic spectrum disorder*, «Journal of Autism Developmental Disorders», 34 (3) (2004), pp. 285-299.

[56] G. Bird, J. Leighton, C. Press, C. Heyes, Intact automatic imitation of human and robot actions in autism spectrum disorders. *Proceeding of the Royal Society of London B Biological Sciences,* 274, pp. 3027-3031. A.F. Hamilton, *Emulation and mimicry for social interaction: A theoretical approach to imitation in autism*, «Quarterly Journal of Experimental Psychology», Special Issue in honor of Uta Frith (2008). A. F. Hamilton, R. M. Brindley, U. Frith, *Imitation and action understanding in autistic spectrum disorder: How valid is the hypothesis of a deficit in the mirror neuron system*, «Neuropsychologia», 45 (2007), pp. 1859-1868.

[57] J. Leighton, G. Bird, T. Charman, C. Heyes, *Weak imitative performance is not due to a functional 'mirroring' deficit in adults with Autism Spectrum Disorders*, «Neuropsychologia», 46 (2008), pp. 1041-1049.

of this work.[58] It is, however, important to stress that a recent paper by Bernier et al (2007) not only demonstrates once more imitative deficits in ASD individuals, but highlights also a positive correlation between the severity of such deficits and the reduced attenuation of mu-rhythm over the motor cortex during action observation, thus corroborating a relationship between imitation deficits and a malfunctioning mirror neuron system in ASD individuals.[59]

Besides, the pivotal role of mirror system in action understanding has been highlighted by the abovementioned study by Cattaneo et al. (2007).[60] This EMG experiment has proven that high-functioning ASD children are unable to organize their own motor acts in the kind of intentional motor chains displayed by typically developing (TD) children. Just as TD children, children with ASD were requested to execute and to observe two different types of action (e.g. eating and placing actions). During both conditions the activity of the mylohyoid (MH) muscle was recorded. The results showed that, as occurred for TD children, there was no MH activity in the children with ASD during the execution and the observation of the placing action; on the contrary, however, they showed a much later activation of the MH while eating and no activation at all when eating was observed.

The relevance of this study is that it shows for the first time that the primary deficit is not in the responsiveness of the mirror neurons to the observation of others' action, but in the impaired organization of motor chains underlying action representation. While children with typical development present specific motor goal hierarchies (e.g. grasping *for/in order* to bring to the mouth), ASD children seem to rely on a more simple sequence of motor goals (e.g. grasp *and* bring to the mouth). This type of differential strategy may account for the lack of a clear-cut deficit in the actual execution of motor acts reported by the literature mentioned above. In any case it may explain why children with ASD seem unable to understand immediately and on the basis of their motor repertoire the other's intentions. Impairment in their motor chain organization in fact mirrors difficulties in sharing the intentional meaning of actions with others. It is very likely that there are various cues (e.g. object semantic, context, etc.) that may help children with ASD in understanding why someone else is doing what he is doing. This type of understanding, however, should be kept distinct from the one generated by mirror neuron activation. The former provides at best a mere associative knowledge, whereas the latter offers a grasp of the motor 'aboutness' of others' actions, enabling an observ-

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[58] See on this point V. GALLESE, M. ROCHAT, G. COSSU, C. SINIGAGLIA, *Motor cognition and its role in the phylogeny and ontogeny of action understanding* (in press).

[59] R. BERNIER, G. DAWSON, S. WEBB, M. MURIAS, *EEG mu rhythm and imitation impairments in individuals with autism spectrum disorder*, «Brain and Cognition», 64 (3) (2007), pp. 228-237.

[59] CATTANEO ET AL. 2007.

er to immediately understand both the goal-relatedness that characterizes the single motor acts and, above all, the overall intention that underpins them.

The fact that an impairment in the mirror neuron mechanism and in the type of comprehension that it affords, may be at the basis of ASD finds support also in studies focusing on the production and recognition of emotions. This data is even more relevant once we consider the role of emotional coloring in primary forms of social cognition.

Since very early on in development, children with ASD display a lack of interpersonal *coordination* of affect (e.g. displays of affect seem to occur at random and not necessarily in the context of social interaction),[61] lack of emotional expressiveness when requested to pose emotionally expressive faces or imitate and *produce* expressions of facial affect on instruction[62] and finally a lack of emotional *understanding* of faces, which emerges especially when the experiments are carried out for the purpose of analyzing the *feel* in the faces to guide performance.[63] Summing up coordination, production and understanding of affect seem to be impaired in ASD.

Children with ASD seem unable to recognize both basic emotions (such as happiness, fear, anger, surprise and disgust) and more complex ones, which are more context and culture dependent.[64] This impairment stems not only

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[61] C. Kasari, M. D. Sigman, P. Mundy, N. Yirmiya, *Affective sharing in the context of joint attention interactions of normal, autistic and mentally retarded children*, «Journal of Autism and Developmental Disorders», 20 (1990), pp. 87-100. M. E. Snow, M. E. Hertzig, T. Shapiro, *Expression of emotion in autistic children*, «Journal of the American Accademy of Child and Adolescent Psychiatry», 26 (1987), pp. 836-838. G. Dawson, D. Hill, A. Spencer, L. Galpert, L. Watson, *Affective exchanges between young autistic children and their mothers*, «Journal of Abnormal Child Psychology», 18 (1990), pp. 335-345. M. Sigman, C. Kasari, J.H. Kwon, N. Yirmiya, *Responses to the negative emotions of others by autistic, mentally retarded, and normal children*, «Child Development», 63 (1992), pp. 796-807. T. Charman, S. Baron-Cohen, J. Swettenham, A. Cox, G. Baird, A. Drew, *Infants with autism: An investigation of empathy, pretend play, joint attention, and imitation*, «Development Psychology», 33 (1997), pp. 781-789.

[62] T. Langdell, *Face perception: An approach to the study of autism.* Unpublished doctoral dissertation, University College, London, 1981. H. Macdonald, M. Rutter, P. Howlin, P. Rios, A. Le Couteur, C. Evered, et al., *Recognition and expression of emotional cues by autistic and normal adults*, «Journal of Child Psychology and Psychiatry», 30 (1989), pp. 865-877. K. A. Loveland, B. Tunali-Kotoski, D. A. Pearson, K.A. Brelsford, J. Ortegon, R. Chen, *Imitation and expression of facial affect in autism,* «Development and Psychopathology», 6 (1994), pp. 433-444.

[63] S. Ozonoff, B.F. Pennington, S.J. Rogers, *Executive function deficits in high-functioning autistic children: Relationship to theory of mind*, «Journal of Child Psychology and Psychiatry», 32 (1991), pp. 1081-1105. P.J. Hobson, J. Ouston, A. Lee, *Emotion recognition in autism: Coordinationg faces and voices,* «Psychological Medicine»*, 18 (1988), pp. 911-923.*

[64] O. Golan, S. Baron-Cohen, Y. Golan, *The 'reading the mind in films' task [Child Version]: complex emotion and mental state recognition in children with and without autism spectrum conditions*, «Journal of Autism and Developmental Disorders», (2008).

from a general difficulty in face-processing,[65] but mainly from a specific difficulty in processing facial expressions of emotions.[66]

If some have suggested that areas belonging to the mirror neuron system may be involved in the general face-processing impairment in ASD.[67] Our current hypothesis focuses on emotional coloring trying to highlight that the child with ASD lacks a defined vocabulary of emotions of the type described above. This child may well enough feel range, but not express it when needed or at the right time, nor in the appropriate way – emotions may have their own grammar (just as there is a motor grammar) and in ASD this grammar may go astray.

Evidence from mirror neuron studies allows to provide a possible neurophysiological grounding to the hypothesis mentioned above: an impairment in mirror neuron systems may bring about an inability to re-experience emotions as bodily states and bring about the lack of that 'emotional feel' which is essential in an infant's early interactions with the world and in building an appropriate grammar of emotions.

McIntosh et al. (2006) used electromyography (EMG) recording of activation of facial muscles during the observation of stimuli and relied on the very well documented phenomenon of automatic mimicry, according to which observing another person's emotional behavior (e.g. observing a smiling face) may elicit the corresponding behavior in the observer (e.g. a smile).[68] Studies have documented how not only automatic mimicry may emerge very early in de-

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[65] G. Golarai, K. Grill-Spector, A. L. Reiss, *Autism and the development of face processing*, «Clinical Neuroscience Research», 6 (2006), pp. 145-160. N.M. Kleinhans, T. Richards, L. Sterling, K.C. Stegbauer, R. Mahurin, L.C. Johnson, J. Greenson, G. Dawson, E. Aylward, *Abnormal functional connectivity in autism spectrum disorders during face processing,* «Brain», 131 (2008), pp. 1000 -1012. N.J. Sasson, *The development of face processing in autism*, «Journal of Autism and Developmental Disorders», 36 (3) (2006), pp. 381-394.

[66] G. Dawson, S. J. Webb, J. McPartland, *Understanding the nature of face processing impairment in autism: Insights from behavioral and electrophysiological studies*, «Developmental Neuropsychology», 27 (3) (2005), pp. 403-424. B. Hubert, B. Wicker, D. G. Moore, E. Monfardini, H. Duverger, D. Da Fonse, C. Deruelle, *Recognition of emotional and non-emotional biological motion in individuals with autistic spectrum disorders,* «Journal of Autism and Developmental Disorders», 37 (2007), pp. 1386-1392.

[67] N. Hadjikhani, R.M. Joseph, J. Snyder, H. Tager-Flusberg, *Abnormal activation of the social brain during face perception in autism*, «Human Brain Mapping», 28 (2007), pp. 441-449.

[68] D. N. McIntosh, A. Reichmann-Decker, P. Winkielman, J. L. Wilbarger, *When the social mirror breaks: deficits in automatic, but not voluntary, mimicry of emotional facial expressions in autism*, Developmental Science, 9 (3) (2006), pp. 295-302. E. Hatfield, J. T. Cacioppo, R. Rapson, *Primitive emotional contagion*, in M. S. Clark (Ed.), *Emotion and social behavior*, «Review of personality and social psychology», vol. 14 (pp. 151-177). Thousand Oaks, CA: Sage 1992.

velopment,[69] but it may also play a relevant role in forms of social interaction such as interpersonal rapport, fast learning and the understanding of others.[70] McIntosh and colleagues analyzed performance on automatic vs. voluntary mimicry of emotion laden facial expressions (i.e. eight angry and eight happy static faces) in a group of adults with ASD compared to a group of typically developing adults matched on gender, chronological age and verbal ability. A total of 28 participants were considered and results indicated an impairment in automatic mimicry, but not in voluntary mimicry in the ASD group as compared to TD. The authors suggest that the impairment in automatic mimicry may be due to a dysfunctional prefrontal mirror neuron circuit.

Another study by Dapretto et al. (2006) considered impairment in emotional understanding in autism using fMRI to investigate neural correlates for imitation of facial expressions in children with ASD compared to TD.[71] Results showed a lack of activation of the mirror neuron circuitry in the inferior frontal gyrus during observation and imitation of faces expressing five different emotions. This indicates that even if both children with ASD and TD children were able to perform the imitation task they may rely on different neural strategies. These authors suggest that in being unable to employ a right hemisphere-mirroring neural circuitry, children with ASD may loose some of the *feeling* of emotional significance and resort to rather cognitive strategies.

6. Conclusions

Numerous studies mentioned above demonstrate that there are at least two distinguishable mirror systems sharing the same direct matching mechanism. This literature highlights also how these systems underpin two types of understanding which play a pivotal role in social cognition, allowing its emergence and shaping its basic forms. The functional properties of the mirror neuron system for action indicates that the actions of others, like our own, possess a specific motor intentional content. It is because of such motor intentional meaning that the actions performed by others (whether they are formed by a

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[69] A. N. Meltzoff, M. K. Moore, *Persons and representation: why infant imitation is important for theories of human development,* in J. Nade, G. Butterworth (Eds), *Imitation in Infancy*, Cambridge University Press, Cambridge, 1999.

[70] J. Decéty, T. Chaminade, Neural correlates of feeling sympathy. Neuropsychologia. Special Issue on Social Cognition, 41 (2003), pp. 127-138. M. Iacoboni, *Understanding others: imitation, language, empathy*, in S. Hurley, N. Chater (Eds.), *Perspectives on imitation: From cognitive neuroscience to social science.* Cambridge, Ma: MIT Press (2005). J. Lakin, T. L. Chartrand, *Using nonconscious behavioral mimicry to create affiliation and rapport,* «Psychological Science», 14 (2003), pp. 334-339.

[71] L. Dapretto, M. S. Davies, J. H. Pfeifer, A. A. Scott, M. Sigman, S. Y. Bookheimer, M. Iacoboni, *Understanding emotions in others: mirror neuron dysfunction in children with autism spectrum disorders*, «Nature Neuroscience», 9 (2006), pp. 28-30.

single motor act or an entire chain of motor acts organized according to specific goal hierarchies) are immediately recognizable to us. As soon as we see someone doing something, either a single act or a chain of motor acts, their movements take on meaning for us thanks to our motor repertoire.

A somehow similar argument holds in the case of our ability to understand another person's emotions: the sight of an expression of disgust or pain is immediately filled with meaning (i.e. that of being an expression *of* disgust or *of* pain) due to our emotional repertoire. Our perception of another's emotional state is directly mapped on this repertoire. It is by virtue of such a mapping that perceived events come to bear for us that emotional coloring which characterizes them.

This does not mean that there aren't other ways of understanding the other's motor and emotional behavior. Neither do we wish to reduce the whole of social cognition to the processes run by the two mirror systems analyzed above. We want instead to stress how primary forms of social cognition are tightly linked to an understanding of behavior heavily relying on our first person abilities for action and emotion. It is because it rests on first person action patterns, to the point that it may be considered as a part of them,[72] that mirror-based action comprehension may reach even at a first stage high degrees of generality and complexity mentioned above, thus enabling to grasp the intentional meaning not only of individual motor acts, but also of action chains, characterized by specific motor goal hierarchies mirroring likewise specific motor intentions. It is because it is grounded on our first person feel that the mirror-based comprehension of the other's emotions allows to immediately share the emotional coloring of the other's gestures and reactions.

Even if mirror-based action and emotion understanding may not explain the whole spectrum of social cognition, it nevertheless allows a clarification of some important aspects of social interchange shedding some light on the early phases of its development. Studies mentioned above on a baby's abilities to recognize and coordinate to certain emotional states of the caregiver highlight the important role of emotion producing and understanding during the early stages of development. Emotional understanding may be considered as a core aspect of an infant's relation with the world and at the origin of those paradigmatic relations with to the world, which are termed *thinking* or *willing* or *perceiving* in adults.[73]

A similar argument holds for the pragmatic comprehension of the other's actions and intentions, which we have seem as supported by the mirror mechanism. Besides studies on children with ASD clearly demonstrate how a def-

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[72] C. Sinigaglia, *Enactive understanding and motor intentionality*, in F. Morganti, A. Carassa, G. Riva (eds.), *Enacting Intersubjectivity: A Cognitive and Social Perspective to Study of Interactions*, IOS Press, Amsterdam (2008), pp. 17-32.

[73] Hobson 2002, 2005.

icit in action and emotion understanding at the pragmatic level may bring to major impairment to the development of social cognition and specifically to those mentalizing abilities that allow to understand the other's behavior through the ascription of emotions, beliefs and desires.

ABSTRACT: *This paper illustrates how social interchange characterized by forms pragmatic understanding and emotional coloring are grounded on mirror mechanisms. Initial paragraphs will outline the anatomical architecture of the mirror neuron system for action in monkeys and humans and their main functions. Paragraph four will introduce the theme of emotional understanding underscoring its relevance in development and illustrating major studies on mirror neurons and emotions, before proceeding to consider specific cases in how social cognition is impaired as in autistic spectrum disorders.*