

2 Enactive Understanding and Motor Intentionality

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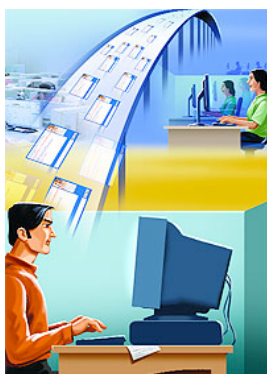
Abstract. Most of our social interactions rest upon our ability to understand the behavior of others. But what is really at the basis of this ability? The standard view is that we understand the behavior of others because we are able to read their mind, to represent them as individuals endowed with mental states such as beliefs, desires and intentions. Without this mindreading ability the behavior of others would be meaningless for us. Over the last few years, however, this view has been undermined by several neurophysiological findings and in particular by the discovery of mirror neurons. The functional properties of these neurons indicate that motor and intentional components of action are tightly intertwined, suggesting that the basic aspects of intentional understanding can be fully appreciated only on the basis of a motor approach to intentionality. This paper has a dual objective: to develop this approach in order to account for the crucial role of motor intentionality in action and intention understanding *below* and *before* any meta-representational ability, and to shed new light on the ontogeny of mindreading, by explaining how the first forms of understanding in infants may be intentional in nature, even without presupposing any explicit and deliberate mentalizing.

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2.1 Introduction

Most of our social interactions rest upon our ability to understand the behavior of others. But what is really at the basis of this ability? How exactly do we understand the behavior of others? This issue encompasses two distinct but complementary questions. In the first place, how do we realize that what we are observing are not pure physical events but intentional movements – in other words, how do we attribute the status of action to the observed movements? And in the second place, how do we understand what type of action these movements are – in other words, how do we identify them as this or that given action?

It is widely assumed in the fields of cognitive science and philosophy of mind that both the recognition of an event as an action, and its identification as that particular action, depend equally on the ability of attributing to others those mental states (beliefs, desires, intentions, etc.) that are supposed to be at the origin of the observed motor behavior and that therefore can render it intelligible and in many cases predictable. Whether such mindreading ability is considered to be related to a more or less explicit use of a “theory of mind”, or to the assumption of an “intentional stance” based on a postulate of rationality, or to a more or less complex form of “simulation” (see [1-2] on this point), is of minor importance in this context. What is important here is that, even though the suggested mechanisms are very different, these various views share the idea that both the status and the identity of an action depends on its connection to specific mental states, so that without the ability to read the mind of others, that is to attribute them with specific mental states, it would be impossible to grasp the intentional meaning of their behavior [3].

However this idea is being radically challenged by an increasing number of studies in the field of what has been called “neurophysiology of action”. Analyses of the functional properties of the cortical motor system and, even more, the discovery of a distinct class of sensory-motor neurons (the so-called *mirror neurons*) have suggested the hypothesis that our understanding of the actions performed by others is primarily based on a mechanism that directly matches the sensory representations of the observed actions with the motor representations of the observer’s own actions. According to the direct matching hypothesis, we primarily understand the actions of others by means of our own motor knowledge: it is this type of knowledge that would enable us to immediately attribute an intentional meaning to the movements of others. This hypothesis does not exclude, of course, that other more complex processes, such as those that characterize our meta-representational abilities, may be at work and play a role in these functions. It simply maintains that mentalizing is neither the *sole* nor the *primary* way of intentional understanding, pointing out that our ability to understand the actions and the intentions of others capitalizes on the same motor knowledge that underpins our own capacity to act.

The present paper aims at exploring such an “enactive” understanding *below* and *before* any mindreading ability. First of all, the basic properties of mirror neurons and their role in intentional understanding will be addressed. It will be argued that the mirror neuron mechanism undermines the usual construal of both action and action understanding by revealing the extent to which intentional and motor components of action are intertwined and how their involvement in action understanding can only be appreciated on the basis of a motor approach to

intentionality. The ontogenetic aspects of intentional understanding that have emerged from some recent studies in developmental psychology will be successively examined and discussed. There is a large consensus that the primary forms of understanding infants develop in the first year of life do not imply any meta-representational ability, nor can they be interpreted as mind reading. However, the nature and reach of this understanding are much-debated topics, and the solutions advanced are often in contrast one to another. It will be finally shown that the mirror neuron mechanism and motor intentionality not only shed new light on the background of mindreading, but also provide a coherent account for its ontogeny, suggesting how the first forms of action and intention understanding may be intentional in nature, being deeply related to the motor expertise infants acquire during their development.

2.2 Mirror neurons for actions: goals and movements

Discovered first in the premotor cortex (area F5) [4-5] and then in the inferior parietal lobule (IPL, areas PF and PFG reciprocally connected with F5) [6] of macaque monkeys, mirror neurons are a specific class of motor neurons which become active not only when an individual performs a specific act (such as grasping) but also when s/he sees it being performed by other individuals. In the macaque monkey the activation of the mirror neurons is connected to the animal's observation of motor acts characterized by an effective hand (or mouth)-object interaction. When the animal observes mimed acts in which no objects are present, or movements performed without any meaning such as raising an arm or waving hands (even if these actions are carried out with the intention of frightening the animal), there is no response from the mirror neurons; this is also the case when the animal observes food or generic three-dimensional objects.

Several electrophysiological experiments and brain imaging studies have provided evidence for the existence of a mirror neuron system for action in the human brain (see for a review [7-8]). It has been shown that in humans too the observation of actions performed by others activates areas and circuits that are involved in motor activity. In particular, it has been demonstrated that the lower part of the precentral gyrus plus the posterior part of the inferior prefrontal gyrus and the rostral part of the inferior parietal lobule form the core of the human mirror system. However, though the mechanism and the localization of the human mirror system are very similar to those of the monkey, its functional properties are different and more sophisticated. Indeed, the human mirror system becomes active also for intransitive and mimicked actions [9] and it is able to code both the goal-directedness of a given action and the temporal aspects of its single movements [10]. The implications of such differences for the development in humans of imitative and communicative capabilities, as well as for the evolutions of language, are extensively treated in [11]. In the following paragraphs I shall focus on the role of mirror neurons in intentional understanding.

The specific congruence of the sensory and motor responses of mirror neurons have led to the hypothesis that they form the basis of a mechanism whereby our brain is able to directly match the sensory representations of the perceived actions with our own motor representations of those actions, and that the primary function of this matching would be to enable us to immediately understand the meaning of

the actions performed by others. But what do we really mean when we talk about the “understanding” and the “meaning” of an action? What kind of understanding can be associated with the direct matching mechanism of the mirror neurons? What does such a mechanism tell us about the meaning, i.e. the “intentional content”, of an action? Is it not misleading to resort to an intentional language by using terms such as “understanding”, “meaning”, and “content”?

These questions can be answered first by considering the motor properties mirror neurons share with the other F5 and IPL neurons. Indeed it has been well known for some time now that the fundamental characteristic of F5 and IPL neurons is that they code goal-directed motor acts such as grasping, holding, manipulating, etc. and not the single movements that compose these acts, as do most of the primary motor cortex neurons which control the fine morphology of movement [12]. For example, many F5 neurons discharge when the monkey performs a motor act such as grasping a piece of food, irrespective of whether it uses its right or left paw or even its mouth to do so; others are more selective, discharging only for a particular effector or grip. However, even when selectivity is at its highest, the motor responses cannot be interpreted in terms of single movements: the neurons that discharge during certain movements (the flexing of a finger, for example) performed with a specific motor goal, such as grasping an object, discharge weakly or not at all during the execution of similar movements that compose a different motor act such as scratching.

A recent study [13] has shown that the goal-relatedness of the F5 neurons not only concern hand- and mouth-, but also tool-mediated motor acts, even in cases where the distal goal of the tool is the opposite of the proximal goal of the hand. The experiment was carried out with macaque monkeys, which were trained to grasp objects using two types of pliers (“normal” and “reverse”), requiring opposite hand movements. 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. Neurons that discharged with normal pliers when the paw was opening discharged when the paw was closing with the reverse pliers: the discharge was always linked to the initial phase of the motor act. Conversely, neurons that discharged with normal pliers when the paw was closing discharged when the hand was opening with the reverse pliers, the discharge being related to the final phase of the motor act.

It is worthwhile noting that in this study hand-related neurons were recorded also from the primary motor cortex (F1). Surprisingly, like F5 neurons, half of F1 neurons have been shown to code the goal-related motion of the pliers, and not the single movements of the fingers of the paw. This finding indicates that the goal-relatedness is a distinctive functional feature upon which the cortical motor system is organized, suggesting a mechanism for the transformation of a motor goal into an appropriate sequence of movements – even when this is opposite to that usually required to achieve such a goal. The goal-related F5 and F1 neurons are connected with different sets of motor cortex neurons controlling the opening and the closing of the hand. Hand interactions with objects as well as the use of the normal pliers reinforce the connections that usually characterize a motor goal such as grasping,

selecting first those neurons that control hand opening and then those that control hand closure. After learning to use the reverse pliers, the opposite connections are reinforced by the success of the tool-mediated motor acts and prevail. Now the neurons that control hand closure are selected first followed by those that control hand opening. In other terms, grasping means no longer: “Close the fingers!” but: “Open the fingers!”

2.3 Basic motor acts and enactive understanding

The fact that at the level of the cortical motor system movements are represented with different degrees of generality and that these representations reveal, albeit in varying ways, a specific goal-relatedness, shows how the meaning, the intentional content of an action does not depend *entirely* and *exclusively* on the mental states (beliefs, desires, etc.) which are supposed to lie at the origin of its execution [14]. There is no doubt that mental states such as beliefs, desires, and intentions can contribute to shaping and refining the intentional content of an action. For example, we can pick up a glass because we are convinced it contains our favorite whiskey and we want to savor it one more time: this action is very different to the action consisting in the same motor act performed with the intention of avoiding that someone picks up the glass if we think it contains a potent poison. It must be said, however, that in both cases the motor act of grasping embodies a motor intentional content that identifies it as being more than just a mere sequence of movements, that is as a goal-related motor act directed to *grasp* a certain *object*, with a certain *shape*, a certain *size*, etc. Quite apart from being the outcome of whatever prior and distinct pure mental state, the act of grasping, like every other basic motor act, is defined by its own goal-relatedness, which renders possible the coherent composition of the various movements and enables us to control them while they are being executed.

This goal-relatedness is coded by F5 and IPL neurons, as well as by a portion of F1 neurons. It cannot be interpreted in abstract or mentalistic terms; on the contrary, it presupposes a motor representation – where the adjective “motor” does not mean simply the content of this representation (as in the case of a mere representation of movement), but its format, its way of representing. This representation has to be construed as a motor goal-related one. It is a goal-related representation because it is characterized by different degrees of generality and although its content refers to movement, nonetheless it cannot be reduced to a single sequence of movements. But is also a motor representation, because the goal is represented in a motor format, as the end-point of a motor act, and although this representation can differ in respect to single movements, nonetheless it must have a coherent motor content that enables it to determine a given behavior and to control its execution. Without such a type of representation, it would be almost impossible to select the appropriate movements for our actions, compose them in the correct sequence and control the final execution. On the other hand, this type of representation enables a movement (like the flexing of a finger, for example), to take on different intentional meanings as it is a part of various acts with different motor goals (such as grasping as opposed to scratching); it also enables different movements (even movements which are diametrically opposite such as opening

and closing one's fingers) to take on the same intentional meaning, as they are part of acts with the same motor goal (grasping).

Such motor representations are evoked also by observing the actions performed by others. As already mentioned, the mirror neuron mechanism directly matches the sensory with the motor representations of the observed actions. It is the goal-relatedness of these motor representations that allows the observer to immediately pick up the motor intentional meaning of the observed actions, i.e. the motor aboutness, which characterizes them as such and makes them comprehensible. The fact that the observation of an action performed by others generates a motor representation that is similar to that which the observer himself would activate if he were planning that action, shows that both representations possess the same intentional motor content and that the status and the identity of a given action, whether observed or performed, depends primarily on this content, at least at the level of basic motor acts.

That is true not only for hand- and mouth- actions, but also for tool-mediated motor acts, even when they involve opposite sequences of movements. In the above-mentioned experiment on the use of normal and reverse pliers [13], both F5 purely motor neurons and also F5 mirror neurons were recorded. The motor and visual responses of F5 mirror neurons possessed the same goal-relatedness, that is that F5 mirror neurons were able to code the distal goal of the pliers as the same (grasping) both from a motor and 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 motor goal-relatedness in the action understanding made possible by mirror neuron activation, indicating how the ability to visually code the goal of the observed movements and the fineness-of-grain of this goal coding depend on the observer's motor expertise.

This is in line with the evidence from a number of brain-imaging studies [15-18] over the last few years; these have shown that activation of the mirror neuron system during action observation is modulated by the observer's motor repertoire. As this repertoire develops, diversifies and becomes increasingly sophisticated, the ability to immediately understand the actions of others develops, diversifies and also becomes increasingly sophisticated. In other words, the more the goal representations are motor fine-grained, the greater the significance acquired by details of the observed actions, which, together with those effectively executed, share the fineness-of-grain of their motor intentional content. It is due to this sharing that action understanding can become extremely detailed – continuing to be immediate and without presupposing the meta-representational abilities which are alleged to be at the basis of mind reading.

The motor format of the goal-related representations also explains why action understanding is not strictly bound to the completeness of the sensory information or to only one sensory modality. Indeed, recordings of single F5 mirror neurons [19] showed that most responded to the observation of hand motor acts even when the final part of these acts, consisting in the effective object-hand interaction, were hidden behind a screen. The evoked motor goal-related representation was always the same, independently of whether the motor act was observed in its entirety or only in its initial phases, allowing the monkey to understand the motor intentional meaning of the observed act in both conditions. In another study [20] F5 mirror neurons were recorded while the monkey observed the experimenter performing a sound-producing motor act and when it heard the sound without seeing the action.

The results showed that a large number of tested neurons responded selectively and congruently to a given motor act (for instance, peanut breaking) only when it was observed, heard or both heard and observed, but did not respond to the sight and sound of another motor act, or to non-specific sounds. This means that visual features are relevant only to the extent that they facilitate the understanding of the motor intentional content of the observed act – but if such understanding could be facilitated by other cues (sounds, for example), the mirror neurons would be able to code the goal-relatedness of the perceived movements even in the absence of visual stimuli.

2.4 Motor chains and intention understanding

The motor acts considered above are defined by single goal-related motor representations. In point of fact, however, our motor behavior usually displays a more complex intentional structure, which cannot be interpreted in terms of a simple sequence of motor acts but presupposes the embedding of the various acts involved into a specific goal hierarchy. Take for example the case of a motor act such as grasping: it may be embedded in diverse actions leading to different final motor goals: eating or placing, for example. In this case the single goal-related motor representation (grasping) becomes part of more complex motor representations related to final goals that differ one from another (grasping for eating or grasping for placing).

Such motor intentional organization has been investigated by recording the activity of IPL motor neurons in macaque monkeys during typical hand grasping movements [21]. The experiment had two conditions: in the first, the monkey grasped a piece of food that had been placed in front of it, and then carried it to its mouth; in the second condition, the monkey grasped an object or a piece of food and placed it in a container. Most of the recorded hand-grasping neurons triggered differentially depending on whether the grasping was a grasping to carry to the mouth or a grasping to move the piece of food from one place to another. The motor selectivity of these neurons and the fact that the motor representation evoked by their activation modulates its goal-relatedness with respect to the final goal of a specific action, not only explains one of the fundamental characteristics of motor organization, i.e. the existence of specific motor chains that guarantees the fluidity of acting, but also provides the building blocks upon which a more complex form of intentional understanding can be constructed. This form, in its complexity, is not restricted to single motor goals, but enables a grasp of the motor intention that makes up the various goals giving origin to real action.

Indeed, in the same study parietal mirror neurons were recorded in the experimental conditions (grasping for eating and grasping for placing) used to test the motor properties of parietal grasping neurons. The results showed that most parietal mirror neurons displayed a clear congruence between motor and visual responses discharging differentially depending on which action the single motor act of grasping was embedded into. Note that in both action execution and observation mirror neurons became active as soon as the macaque's paw or the experimenter's hand assumed the shape necessary to grip the food or other objects. The fact that the visual stimulus elicited the same set of motor goal-related representations that compose the motor intention responsible for the execution of

the entire motor chain suggests that the monkey was immediately able to understand the whole motor intentional content of the observed action, and to anticipate its final goal, from the onset of the experimenter's initial movements. There is no doubt that the context (presence or absence of containers, the type of object to be grasped, etc.) provides relevant visual cues. However, these latter were interpreted in terms of possible motor chains that were not selected on the basis of an all-or nothing mechanism, but presented varying degrees of plausibility that could change depending on the circumstances, thus showing the typical plasticity that characterizes any intentional motor behavior.

An fMRI experiment [22] provided evidence that also the human mirror neuron system is able to grasp the motor intentions of others. Volunteers were presented with three different visual stimuli: a hand grasping a mug with different grips (precision or full hand), two different contexts (teapot, mug, plate, arranged as if someone were about to have tea, or had just finished) and a hand grasping a mug with different grips in different contexts (to indicate grasping the mug to drink from it, or to tidy it away). The results showed that the condition of hand actions embedded in context, compared with the other two conditions, produced a higher activation in the caudal part of the inferior frontal gyrus, in the region which constitutes the frontal node of the human mirror neuron system. This suggests that this system is able not only to code single motor acts, but also to code the general motor intention with which the single motor acts are performed (for example, grasping-for-drinking or grasping-for-tidying-away).

It is worthwhile adding that a series of EMG experiments [23] has very recently shown, albeit indirectly, that motor intention understanding in humans is based on a motor chain organization similar to that found in monkeys and, even more importantly, that its impairment is at the basis of one of the core deficits that characterize the Autistic Spectrum Disorder (ASD). Typically developed (TD) and high-functioning autistic children were requested to execute and to observe two different actions: the first, eating, was to grasp a piece of food with the right hand from a plate, carry it to the mouth and eat it, while the second, placing, was to grasp a piece of paper placed on the same plate and put it into a box. During the execution and observation conditions of both actions the activity of the mouth-opening mylohyoid muscle (MH) of the TD and autistic 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 TD children as early as the reaching phase, whereas no MH activity was recorded in the execution and observation conditions of the placing action. As occurred in the TD children, there was no MH activity in the autistic children 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.

There are a number of studies, using different techniques, [see, for instance, 24-27] whose results support the hypothesis that a core deficit of ASD, the inability to understand the intentional meaning of the behavior of others and therefore to relate to them in an ordinary way, depends on a malfunctioning of mirror neuron system. The EMG experiments, however, indicate, 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' [23]. The fact that the autistic children did not show MH activity

during the entire reaching and grasping phases of eating, becoming active only during the bringing-to-the-mouth phase, indicated that they were not able to represent the entire action to be executed as an intentionally organized motor chain, but only as a simple sequence of unrelated single motor acts.

This inability did not determine any actual impairment during the execution of either action, given also the simplicity of the required tasks. During observation, however, the autistic children's ability to disambiguate the eating action from its onset was impaired, and this made them unable to understand the motor intention with which the experimenter was grasping the pieces of food or of paper. In fact, MH activation did not occur during the observation of either eating or placing. It is very likely that there are various cues (object semantic, context, etc.) that help autistic children to understand why the experimenter was doing what he was doing. This type of understanding, however, should be very clearly distinguished from that generated by motor knowledge. The former provides at best a merely associative knowledge, whereas the latter gives a grasp of the motor aboutness of others' actions, enabling to understand both the goal-relatedness that characterizes the single motor acts and, above all, the overall intention that underpins them.

2.5 Before mindreading: the ontogeny of intentional understanding

Up to now I have considered what the mirror neuron mechanism suggests may be below mindreading. But what does this mechanism tell us about what happens before mindreading, and in particular what happens before mindreading from an ontogenetic rather than a phylogenetic point of view (on the latter issue see [28]; see also [29])? Are the first forms of intentional understanding in infants to be construed as modalities of acting in way that are consistent with more mature motor understanding of goal-related actions? Does motor intentionality play a role in shaping the ontogeny of intentional understanding?

Over the last few years, numerous studies have demonstrated that the ability to read the mind of others could in fact appear at a very early stage in the infant's development. A recent looking-time experiment, for instance, revealed the covert ability of 15-month-old infants to predict an actor's behavior on the basis of her true or false beliefs [30]. However, it is widely accepted that the forms of intentional understanding infants develop in the first year of life are related to the goal-relatedness of the observed movements and that they cannot be interpreted in terms of mindreading [31-33]. For example, a series of looking-time experiments have shown that 6- and 9-month-old infants are able to distinguish between the goal-relatedness of some basic hand motor acts and their kinematics: infants in both age groups looked longer at the hand grasping a new object, but which followed that the same trajectory as in of the habituation test (new goal/old path), than at the hand following a different trajectory, but which grasped the same object as in the habituation test (old goal/new path). This did not happen when the observed action involved inanimate objects (a claw, for instance) or was incoherent from a motor point of view (the back of the hand was approached to the object instead of the open palm) [34-35]. These findings suggest that by their ninth month infants have a 'store of knowledge' that does not imply any meta-representational ability and allows them to be better tuned to the goal-related than to the spatial and temporal properties of the basic motor acts performed by others.

In spite of such large consensus, the hypotheses advanced to account for the nature and the reach of this kind of knowledge and its function in intentional understanding in infants are very different, and often in conflict one with another. For the sake of simplicity, I shall first introduce and discuss three of the most prevalent views, then elaborate and motivate a fourth hypothesis to show that motor intentionality is not only crucial for the development of intentional understanding, but also provides a theoretical unitary and neurophysiologically sound framework in which to construe the various and ever-growing body of evidence coming from development psychology research.

According to the first view [see among others 36-38], it is not a contradiction in terms to attribute the ability to detect the intentional nature of the actions performed by others and to ascribe intentions to them to 6- and 9-month-old infants, as long as it is recognized that the fully developed concept of intention is gradually acquired at a much later stage. In the first place, an infant's detection of intentions should not be confused with more mature meta-representational understanding. While the latter mechanism presupposes the ability to see intentions as mental representations independent from the actual execution of actions and to appreciate both their causal role and satisfactory conditions, the former is based on a notion of intention which does not presuppose any sharp distinction to the correlated notion of desire, but has to be interpreted as an undifferentiated "pro-attitude", a "conation", intimately tied to given actions and objects.

Though it must be recognized that this view emphasizes the differences between the mechanisms involved in the development of intentional understanding, showing how at the beginning they are not closely related, and only become integrated at a later stage, the precocious and undifferentiated concept of intention it appeals to is neither a necessary nor a sufficient condition to account for the first forms of understanding in infants. It is not a necessary condition: what the looking-time experiments show is that 6- and 9-month-old infants are able to detect the goal-relatedness of the observed motor behaviors without needing to attribute an "undifferentiated" pro-attitude to the latter. Even without such an attribution, the infants would have been able to distinguish between both the different goals of the observed motor acts [34] and also the congruent and non-congruent ways to achieve them [35]. Moreover, the undifferentiated nature of this pro-attitude explains why it cannot be considered as a sufficient condition, as it ends up assuming what it should in fact be accounting for, i.e. the intentional link between the goal and the motor means on which the status and the identity of a given action depends. How could the infants have rendered the observed motor events intelligible and understood their goal-relatedness simply by ascribing a void conatus towards some unspecific objects to these movements? To what extent would such an ascription have enabled the infants to disambiguate the sensory information and to code its peculiar content?

The second view hypothesizes that the development of intentional understanding is rooted in at least two different systems: first, in a low-level system for detecting statistical regularities in the actions of others would enable the identification of relevant units in the observed behavior stream; a high-level system would then facilitate the making sense of these units in terms of second-order mental states, thus achieving a genuine intentional understanding [see among others 39-40]. These systems would have independent evolutionary and developmental origins,

and only later become intertwined. The infant's abilities in action understanding would therefore reflect an evolutionary archaic competence to monitor the behavior of others and to keep track of the statistical regularities embedded therein, while the ability to read the mind of others might have its own evolutionary history, probably connected with the emergence of the representational structures that support human language [39]. The evolutionary and developmental advantage of the meta-representational system would therefore not have been the generation of a large set of fundamentally new behaviors, but the greater flexibility offered in organizing and deploying existing behavioral elements, thus putting old behavioral patterns to new uses.

There is no doubt that the hypothesis that systems unrelated to meta-representational abilities may have evolved to detect the same kinds of behavioral regularities that will later be interpreted by mature mind readers in terms of intentions may sound very appealing from both an evolutionary and a developmental point of view. Indeed, it challenges the notion of a rigid cognitive discontinuity between the various ways of action understanding, claiming that the advantage of the emerging meta-representational abilities would have been to refine the behavioral abilities, increasing their flexibility in the planning of ones' own actions as well as in the understanding of those performed by others. With regards the low-level system, however, it must be said that, like the previous view, this hypothesis takes for granted what should rather be accounted for. Attempting to explain the first form of infant understanding by falling back on the "statistical regularities" that are thought to characterize biological movements seems rather an indication of the existence of a problem than its solution. How do 6- and 9-month-old infants acquire the capacity to detect such regularities and to what extent do these regularities allow the infant to code sensory information in intentional terms? Just how statistically regular must the observed hand-object contacts (for example) be to enable infants to understand the specific goal-relatedness of reaching and grasping movements performed by others? And why should those connected to the various hand-object interaction modalities prevail, rather than those connected to the cinematic aspects of observed movements, to their spatial-temporal characteristics, etc.? Surely it is the progressive development of the ability to act that permits the infant to perceive these regularities and not others – and therefore it is from that ability, rather from the simple regularities observed, that the first forms of understanding would depend?

2.6 Teleological stance and motor intentionality

The third view, known as "teleological stance" hypothesis, seems carry greater weight today. It is based on a series of looking-time experiments that used computer-animated events with 2D geometric figures (circles and rectangles) behaving in ways adults have no difficulty in describing as goal-related [see for a review 41]. In one of these experiments, for example, 12-month-old infants were habituated to seeing a small circle approaching a large circle by jumping over an obstacle separating the two. During the test phase the obstacle was removed and infants were presented with two different test displays: in the first, the small circle approached the large circle along the same trajectory as before, while in the second the small circle approached its target along a straight-line trajectory. Infants looked

longer at the trajectory in which the small circle jumped, suggesting that they found it curious because there was no longer any need to jump as the obstacle had been removed and therefore the trajectory had become inefficient, whereas the straight-line trajectory matched their expectations as it was considered the most efficient way to approach the target in the new situation [42].

According to the authors of these experiments, such findings show that by 12 months of age infants are equipped with an inferential system, the teleological stance, enabling them to ascribe goal-relatedness to the movements of a wide range of entities on the basis of a “rationality principle” that would provide the well-formedness criteria for action interpretations. This principle would incorporate two basic assumptions about the intentional nature of action – i.e. that (i) its primary function is to bring about some particular change of state in the world, and that (ii) any agent will employ the most efficient means available within the constraints of a given situation (equifinal variation of action) –, thus specifying the types of perceptual cues whose presence can impel infants to infer the goal-relatedness of the observed movements. In particular, evidence that individual has the ability to adaptively modify his/her conduct to a change in environmental conditions, attaining the same goal in the most efficient manner in the new condition, should be taken as a strong indication of the goal-relatedness of the observed movements – independently of the agent that has performed them, be it a human being or a 2D object.

The intentional nature and reach of the various forms of understanding thus result as sourcing from a unique principle which, though applied to diverse dominions, would still be the same for all. In fact, though the teleological stance does not imply any mentalizing, involving inferences on factual reality (action, goal-state and current situational constraints), it would share the principle of rationality with the “intentional” or “mentalistic” stance. This would account for both the surprising sophistication of early intentional understanding and also the development of mindreading abilities, suggesting that infants start to assume a mentalistic stance when their cognition becomes sufficiently flexible to represent fictional and counterfactual world states and to apply the inferential principle of the earlier (teleological) stance to them [41].

In spite of its elegance and simplicity, the teleological stance hypothesis also presents some difficulties. First of all, the rationality principle that rules the action interpretation narrows down the goal-relatedness attribution to only the most efficient of the possible behaviors in any given situation, so identifying the first forms of intentionality with the efficacy of the conduct to which they supposedly give origin. This may be true in cases of chasing such as those of the experiment considered above, in which the goal relatedness of the observed movements can be measured only in terms of ‘minimal action’ or ‘the shortest path’. But what happens in the case of more specific interactions, such as, for example, the hand-object interaction that is typical of reaching and grasping? A very recent looking-time study on macaque monkeys carried out with the same experimental paradigm used in previous work on human infants has shown that the tested animals were able to detect the efficacy of observed hand goal-related motor acts only when these latter belonged to their motor repertoire, or were at least compatible with its motor expertise [43].

Therefore it can be shown that goal-relatedness and efficacy do not always coincide, but in the case of basic motor acts such as grasping the latter presupposes

the former. On the other hand, the abstractness of the behavioral cues and the fact that in very simple situations they would suggest the goal-relatedness of the observed movements, does not in itself guarantee the generality of the proposed inferential system. Even the supporters of the teleological stance were hard put to it to account for the results of the above quoted looking-time experiments regarding the observation of hand motor acts and in which the goal attribution did not imply the effective presence of either of the two perceptual cues presupposed by the rationality principle, to the point that they had to call on the role played by the previous perceptive and motor experience of the 6- and 9-month-olds, emphasizing how 'natural grasping events familiar to infants often exhibit equifinal modification of action as a function of environmental changes when lifting, transporting, shaking etc. of variable objects grasped in different situations' [44].

The question remains whether the recourse to 'pure reason' is still legitimate in cases such as these, or whether it would not be simpler and more economic to call on the motor knowledge of 6- and 9-month-olds, given also the fact that it can drive the infants' understanding of the goal-relatedness of observed movements without presupposing any inferential system. This in fact is the direction taken by a good number of more recent studies. In particular, it has been shown that infants are sensitive to the goal-relatedness of movements performed by others even at 3 months of age, but only when facilitated by previous motor experience [45]. The fact that infants capitalize on their own motor knowledge for intentional understanding is also strongly corroborated by a gaze-recording experiment indicating that, like adults, 12-month-old infants produce proactive goal-directed eye movements when observing a goal-directed placing – which did not occur when they observed self-propelled objects following the same trajectory as before but without the presence of any human effector [46].

This is not to deny the importance of the data produced in support of the teleological stance hypothesis, nor does it exclude that forms of inference such as those indicated above may play an important role in the development of infant understanding. It simply implies the need to realize that motor knowledge is at the basis of a form of intentional understanding, which has to be recognized as *original* and perhaps as *primary*. This is particularly true as it not only permits the identification of the various degrees of goal sensitivity that children demonstrate in their first year of life, but also throws light on a key point in the development of intentional understanding, which is marked by the emergence of the capacity of the capacity of interpreting the observed motor acts not only as individual acts but also in terms of hierarchically organized motor goals. It been known for some time that 9/12 months of age marks a crucial phase in the development of infants' ability to represent motor goals in planful manner. More recently, it has been shown that by 12 months of age, infants are able to detect the hierarchical goal structure of a sequence of motor acts [47]. But the most important point is that the investigations of 10-month-old infants looking times have revealed that only the infants who were able to organize, by themselves, determined sequences of hierarchically organized motor acts were able to recognize the same sequences performed by others [48]– showing once again the crucial role of motor intentionality in the ontogeny of intentional understanding.

2.7 Concluding remarks

Taken together, neurophysiological findings and development psychology research suggest that motor intentionality is at the basis of the action and intention understanding below and before mindreading. The functional properties of the cortical motor system and the mirror neuron mechanism indicate that the actions of others, like our own, possess a specific motor intentional meaning that cannot be reduced to the pure mental states (beliefs, desires, intention, and so on) that might have been at the origin of their execution – at least at the level of basic actions. It is because of their motor intentional meaning that the actions performed by others, whether they are formed by single motor acts or entire chains of actions organized by 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, his/her movements take on meaning for us, whether he/she likes it or not, and regardless of what he/she has in mind.

This does not mean that the role that mind reading ability plays in intentional understanding must be denied. Our social conduct depends largely on our ability to read the mind of others. However, whichever the underlying mechanism may be, this meta-representational ability does not account for the full extent of intentional understanding. Nor can it be assumed as being paradigmatic. If it did, we would have to assume that without any explicit or deliberate mentalizing the actions of others would be basically opaque for us, mere physical movements devoid of any intentional meaning whatsoever. This however is not the case, and the mirror neurons mechanism shows how our motor knowledge enables us to immediately understand them.

Such enactive understanding is not only different in nature and content from the modalities of mind reading that have traditionally been taken into consideration, it also helps clarify their ontogeny, throwing new light on the first forms of intentional understanding that infants develop during their first year of life. Many of the most recent experiments show clearly how the sensitivity demonstrated by infants to the goal-structure of action while observing the movements of others depends on the level of development they have reached in their own capacity to act. The very transition to more articulated forms of understanding, that enables them to grasp the meaning of individual acts according to the overall actions in which they are embedded appears to be marked by the capacity to represent entire chains of actions with a specific goal hierarchy, and not just single unrelated acts; this allows them to plan and implement action with increasingly complex motor and intentional content. This is a key transition in the development of intentional understanding that once again reveals the crucial role of motor intentionality. This does not mean to say that the entire ontogeny of mind reading must be reduced to the development of motor intentionality. It is simply to underline how a motor approach to intentionality, such as that suggested by the mirror neuron mechanism, may, for the first time, show the way to rethinking the basis and the development of intentional understanding within a unitary theoretical and neuro-physiologically grounded framework.

2.8 References

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