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Positing a space mirror mechanism: intentional understanding without action?

Abstract: *Recent evidence regarding a novel functionality of the mirror neuron system (MNS), a so-called 'space mirror mechanism', seems to reinforce the central role of the MNS in social cognition. According to the space mirror hypothesis, neural mirroring accounts for understanding not just what an observed agent is doing, but also the range of potential actions that a suitably located object affords an observed agent in the absence of any motor behaviour. This paper aims to show that the advocate of this space mirror hypothesis faces a crippling dilemma. Either what observed agents can do remains underdetermined by space mirror representations, and no proper understanding of action potentiality is gained; or, if it is just understanding of potential motor acts that is achieved through the sensorimotor representations generated by shared object-related affordances, the very explanatory role of space mirroring is compromised.*

1. Introduction

The mirror neuron system (MNS henceforth) is believed to play a crucial role in explaining how it is that we come to understand other people's actions, intentions and emotions. Mirror neurons are sensorimotor neurons that fire both when an agent executes a goal-oriented motor act (such as grasping, biting or moving an object) and when such a motor act is observed—provided that both observer and observed share the same motor abilities. According to the mirror neuron hypothesis, this coupling between perception and off-line motor execution is the result of a direct matching mechanism: the MNS. Witnessing the execution of a goal-oriented motor act induces, in the observer's brain, a pattern of neural activation similar to the pattern that occurs during the execution of that act. The tokening of such a similar pattern generates a representation that endows the observer with an immediate understanding of the witnessed motor act, regardless of the morphology of the movement.

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Plainly, however, the same witnessed motor act (e.g., grasping) may serve different goals (e.g., grasping for eating or grasping for placing aside) and hence be the result of different intentions. A revised version of the action MNS hypothesis resolves this problem by invoking a particular subset of mirror neurons. These “logically-related mirror neurons” fire differently depending on which motor act typically follows the initially observed one in a particular context. In a context in which, e.g., tea is about to be served, the activation token that results from witnessing the motor act of grasping is shown to be different from the activation token that results from witnessing the same motor act in e.g. a context of doing the washing-up. On this version, the patterns of activation replicated in the observer’s parietal lobe when witnessing a goal-related motor act are thus organized in pre-wired motor chains, which differ depending on the motor intention with which the act is executed (Fogassi *et al.*, 2005; Iacoboni *et al*., 2005).[1]

A recent paper by Costantini and Sinigaglia (2012) takes the MNS hypothesis a step further by showing that grasping-like affordance relations (i.e., the relations between features of an object and an agent’s relevant motor abilities) depend not only on the object’s falling within an observer’s peripersonal space (i.e., the observer’s own reaching space) but also on its falling within the peripersonal space of any observed agent, *even in the absence of any motor act* (see also Caggiano *et al.,* 2009). This so-called “mirror mechanism for the peripersonal space” seems to be triggered by the sight of an agent and a suitably located object without requiring that the agent perform any goal-directed motor act involving the object—again, as long as the observer is endowed with the same motor abilities as the observed agent. The observed agent’s available *potential* for action is thus mapped, they claim, onto the observer’s own motor repertoire. This suggests, Costantini and Sinigaglia further contend, that the observer understands the range of potential actions available to the observed agent from the inside—as the set of potential actions is partially constituted by the shared object-related affordances in the observed agent’s peripersonal space (Costantini & Sinigaglia, 2012, p. 447–50).

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[1] In what follows, whenever I refer to the action MNS hypothesis, I shall be referring to the version of the hypothesis that incorporates these findings. I will maintain the qualifier “revised” only at places where the context makes it important to stress their relevance.

The aim of this paper is not to challenge the plausibility of this claim *per se* or the plausibility of the alleged general MNS mindreading functionality. Rather, I highlight a tension between the new *space* mirror hypothesis and the *action* MNS hypothesis with regard to the right level of action individuation, and hence potential action individuation, required for granting understanding of either kind. My argument takes the form of a dilemma. On the one hand, if it is only through the activation of logically-related mirror neurons that we can explain the understanding of an (otherwise intention-plural) witnessed goal-directed motor act, then it will be difficult to justify, by the action MNS theorist's own lights, that, in the absence of any motor act, the representations generated by the space mirror mechanism can contribute in any specific way to the explanation of the understanding of potential actions—inasmuch as this requires an understanding of potential motor intentions. On the other hand, if it is just understanding of potential motor acts, and not potential motor actions, that space mirror representations account for, and we thus conceive of them as sensorimotor representations of object-related affordances, then all the explanatory work appears to be done by the enactive dynamics of such affordances, leaving no significant explanatory role for the space mirror hypothesis itself. The notion of shared object-related affordance also seems better suited for theoretical treatments in which neural predictive coding and not neural mirroring is the key explanatory property.

The paper is organized as follows. In the first section, I introduce the MNS hypothesis and detail how it has evolved hand in hand with new experimental results. In Section 3, I then sketch three versions of what I would here like to call "the intentional worry": Csibra's (2005, 2007), Borg's (2007) and Jacob's (2008)—together with a powerful reply by Sinigaglia (2007). The intentional worry amounts to questioning the idea that motor mirroring can directly transform motor-act perception into a univocal representation of an observed agent's intention.[2] In Section 4, I present evidence that Costantini and Sinigaglia (2012) take to support the new *space* mirror hypothesis and discuss their suggestion that 'the mirror mechanism for the

[2] All these versions of the intentional worry thus question the idea that action mirroring is a sufficient condition for intentional understanding. See also Jacob and Jeannerod, 2005. Some authors (e.g. Jacob, 2008) also argue that action mirroring is not even a necessary condition for generating this type of understanding.

peripersonal space appears to bridge the gap between the motor-based affordance perception and the mirror-based action understanding, playing a key role in understanding *from the inside* what another individual is really doing' (*ibid*., p. 450). In Section 5, I construct the first horn of the aforementioned dilemma. Finally, in Section 6, I argue for the claims of the second horn. I do so by providing what I take to be a more charitable interpretation of how the new space mirror functionality ought to be understood—an interpretation that locates the proposal within an embedded, embodied and extended view of cognition and an enactive view of perception.

2. The MNS hypothesis

Mirror neurons were first discovered in the ventral premotor cortex of macaque monkeys, located in an area called F5 (Rizzolatti *et al.*, 1996; Gallese *et al.*, 1996) and later on in a rostral inferior parietal area, area PF (Gallese *et al.,* 2002) reciprocally connected with area F5 (Rizzolatti & Luppino, 2001). Neurons in area PF are also connected to others in the superior temporal cortex, specifically in the superior temporal sulcus. This whole cortical circuit, the MNS, seems to be dedicated to the generation of motor representations both when a goal-directed motor act is executed and when one is witnessed—but not when performing or witnessing movements which do not have a goal or when an action is pantomimed. In the case of witnessing a goal-directed motor act, the motor neural activation in the observer's brain replicates the motor activation that occurs during the execution of the act, but without issuing any commands to act.

A similar circuit seems to be present in humans, where neurophysiological and behavioural evidence has been taken to confirm that the MNS hypothesis sheds light on a variety of cognitive capacities such as understanding language (Rizzolatti & Arbib, 1998) and learning to imitate (Rizzolatti *et al*., 2001), as well as on understanding actions and intentions (Gallese & Goldman, 1998; Goldman, 2006. See also Rizzolatti & Craighero, 2004 for a review).[3] With regard to this last line of

[3] There are some differences between MNS functionality in humans and in monkeys. The array of actions sensitive to MNS activation is wider in humans and it seems to be more sensitive to the timing

research—the subject of this paper—it is important to stress that F5 premotor neuron activation patterns seem to code not the morphology of the observed motor act, i.e., not the individual fine movements of a given motor act, such as the flexing of the fingers, but the action type. When, e.g., grasping a piece of food, the same mirror neurons fire in the observer's MNS regardless of the particular movements the observed agent performs, e.g., whether it is with the right or left hand, or with the mouth (Rizzolatti *et al.*, 2000). Even when the movements required to execute a particular motor act, e.g. grasping, are the opposite of standard movements, as in experiments involving reverse action pliers, all the same neurons in the premotor ventral cortex fire, maintaining the same sequence with respect to different phases of the grasping in relation to the goal-related action of the pliers (see Umiltà *et al.,* 2008). MNS activation thus suggests the existence of a direct match between the perception and the execution of a goal-related motor act. It has been taken to constitute the neural basis of the processes by which agents make sense of behaviour witnessed in others.

Initial overenthusiastic claims made it sound as if MNS activation was the key to explaining the automatic and non-inferential way in which we seem to "read" the minds of others (Gallese & Goldman, 1998). Recently, a more cautious approach has been adopted. Both Gallese and Goldman, albeit separately, now acknowledge that elements other than MNS activation—such as projection and theorizing—play an important role in what is taken to be the right theory of mindreading (Gallese, 2003; 2007; Goldman, 2006). Even so, the spirit of the original hypothesis remains pretty much the same. The central claim is still that mirror neuron activation directly matches what an agent is observed to do in terms of the goal that typically characterizes the observed motor act, thus endowing the observer with an understanding of what the observed agent is doing (Rizzolatti, G. & Sinigaglia, C., 2008b). Two crucial sets of experiments have contributed to making the MNS hypothesis more plausible in this respect: Iacoboni *et al*. (2005) and Fogassi *et al.* (2005). These experiments give rise to a revised and improved version of the MNS hypothesis.

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of the observed motor acts. See e.g. Miall (2003) and Rizzolatti & Sinigaglia (2008a). Such differences can be ignored for the purposes of this paper.

The experiments carried out by Fogassi *et al*. (2005) were based on recordings of single-cell firing patterns in macaque monkeys. They tested the sensitivity of parietal mirror neurons to the intention with which a single motor act of hand–grasping was executed: whether it was hand–grasping for eating or hand–grasping for placing aside. They showed that inferior parietal lobule mirror neurons were sensitive to the motor intention from the very beginning of the movement. They triggered pre-wired motor chains that were different for each of the two motor intentions with which the grasping motor act was carried out.[4]

In their experiments performed on humans, Iacoboni and collaborators report the same phenomenon. Through the use of fMRI, they recorded the activation of lateral fronto-parietal circuits of the MNS while subjects watched a video of an agent lifting a cup in two different contexts. In one context, the clues suggested that drinking was the motor intention behind the lifting. The clues in the other context, in contrast, suggested that the relevant action was placing aside for washing. The study suggests that the pattern of activation of parietal mirror neurons that occurs when witnessing the motor act of grasping in a drinking context is different from the pattern of activation that occurs when the witnessed motor act forms part of placing the cup aside to be washed.

In both sets of experiments, the difference in patterns of activation was taken to be due to the particular subset of logically-related mirror neurons that was triggered, which, in turn, seems to depend on the goal related to the observed motor act in the given context. The relation between the motor act and its goal, however, is not one of logical necessity, but rather it is probabilistic or inductive. The relation is between two motor acts, the second functionally or typically related to the first, observed act. Iacoboni *et al.* (2005, p. 533) sum up their findings as follows:

> Our results suggest that a subset of mirror neurons in the inferior frontal cortex discharge in response to the motor acts that are most likely to follow the observed one. In other words, … there is activation of classical mirror neurons, plus activation of another set of neurons coding other potential actions sequentially related to the observed one. This interpretation of our findings implies that, in addition to the classically described mirror neurons that fire during the execution and observation of the same motor act (e.g., observed and executed grasping),

[4] See also Cattaneo *et al.* (2007).

> there are neurons that are visually triggered by a given motor act (e.g., grasping observation), but discharge during the execution not of the same motor act, but of another act, functionally related to the observed act (e.g., bringing to the mouth). Neurons of this type have indeed been previously reported in F5 and referred to as "logically related" neurons … The present findings not only allow one to attribute a functional role to these "logically related" mirror neurons, but also suggest that they may be part of a chain of neurons coding the intentions of other people's actions.

The discovery of these chains of pre-wired mirror neurons strengthens the MNS hypothesis, which can thus account for different motor intentions behind a particular motor act. Or so it seems.

3. The intentional worry

Despite these, without a doubt very exciting, experimental results, some philosophers and cognitive scientists still remain sceptical about the claim that action MNS activation can explain the observers' apparent understanding of an observed agent's intention. Philosophers tend to distinguish between basic actions, e.g., pressing a switch, and non-basic actions, e.g., turning on the light. The latter are performed by carrying out the former. They also often make a parallel distinction between motor intentions (or "intentions in action") and "prior" intentions. They usually characterize a motor intention as an intention to carry out a basic action (Searle, 1983; Pacherie, 2000). The idea is that while basic actions are the result of an agent's motor intentions, non-basic actions are controlled by the agent's prior intentions. What still remains contentious is thus whether action mirroring can generate the kind of representations involved in making sense of an observed agent's prior intention.

A great concern is the exact relationship between lower-level mirroring and the higher-level perception-based theorizing that lies at the heart of the mirror neuron hypothesis. In Csibra's words (2007, pp. 446–447):

> All these findings reflect a tension between two conflicting claims about action mirroring implied by the direct-matching hypothesis: the claim that action mirroring reflects low-level resonance mechanisms, and the claim that it reflects high-level action understanding. The tension arises from the fact that the more it seems that mirroring is nothing else but faithful duplication of observed actions, the less evidence it provides for action understanding; and the more mirroring

represents high-level interpretation of the observed actions, the less evidence it provides that this interpretation is generated by low-level motor duplication.

This quote nicely illustrates what I call here 'the intentional worry'.[5] The intentional worry is just one species from a genus of concerns that relate to the idea that certain low-level cognitive properties or events are insufficient on their own to account for certain higher-level cognitive properties or events, which thus remain underdetermined. Marr's computational theory of vision is usually invoked to illustrate this class of problems, since *prima facie* the 2D impressions our retina makes of perceived objects and scenes in the world are not sufficient to create the 3D perceptual representations that constitute what an agent sees. In the same way in which, e.g., a set of edges and regions in space can be the lower-level representation of very different 3D objects, the same mirroring triggered by the observation of some agent's motor behaviour can represent very different actions, depending on the intentions with which such motor acts are executed. Interestingly, the intentional worry acquires its sharpest form precisely against the experimental results that seemed to settle the worry in the first place—those results that marked the beginning of the revised MNS hypothesis that I sketched in Section 2.

Csibra (2007), for instance, points out that it is not clear that the MNS activation demonstrated by Fogassi's and Iacoboni's sets of experiments provides conclusive evidence that such mirroring could be interpreted as being directly responsible for an observer's understanding of what an observed agent is doing, in the sense of understanding the (prior) intention with which the agent executes a particular motor act. Instead, he claims, the experiments show that MNS activation is somehow involved when witnessing an agent executing a motor act, but this may only reflect the perceptual reconstruction of the agent's intention at a higher cognitive level. Csibra questions the MNS as a direct, i.e., un-interpreted, matching mechanism between sensory and motor information. Instead, he treats MNS activation as the result of a transformation of an already perceptually understood intention into a motor format. In a classic passage (Csibra, 2007, p. 441), he contends:

[5] See also Csibra, 2005; Jacob & Jeannerod, 2005; and Jacob, 2008.

> Just as the *mechanism* of imitation is always emulation at a lower level, the *mechanism* of motor mirroring is always reconstruction. There is no mysterious mirroring process that directly transforms action observation into motor code. Rather, the observed action is analyzed at some level of precision and the result of this analysis is mapped onto the observer's motor system. One can call this mapping process 'direct matching' (Rizzolatti et al., 2001) and such mappings may be established by 'direct' associations, but what is mapped during mirroring is not an uninterpreted signal but a description of the observed action at some level of the action hierarchy. The fine details of the resulting motor activation in the observer do not directly originate from the observation but are reconstructed from this description.[6]

Jacob (2008), arguing along the same lines, identifies a tension between the original MNS hypothesis, based on the idea of motor simulation as a way of enabling the observer to *retrodict* the intention of the observed agent's motor act in light of the movements observed, and the revised MNS hypothesis, where logically-related neurons seem to be playing a very different role, namely, the role of a *predictive* mechanism—predicting the next most likely motor act given a particular context. Following an argument similar to that of Csibra, a possible interpretation of MNS activation in the light of the new experiments, Jacob further contends, is that such activation presupposes, rather than generates, a representation of the observed agent's (prior) intention derived from the visual information provided by the context (see also Jacob & Jeannerod, 2005).

Borg (2007), in another version of the intentional worry, argues that the very idea of context-dependent functionally-related motor acts only makes sense by appealing to the (prior) intention of the observed agent—precisely what that context-dependent connection between motor acts is supposed to explain. First of all, she claims, not all intentions have a set of typical, functionally-related motor acts associated with them. I can grasp a teacup with the intention of washing it or with the intention of looking at it just to see, for instance, whether it is clean. Secondly, different patterns of MNS activation should, according to the new hypothesis, encode different overall intentions. Yet, an agent may have the same intention (e.g., to tidy up) while executing very different motor acts. Lastly, Borg argues, one and the same pattern of MNS activation, including the firing of the same logically-related neurons, may still correspond to very different intentions. A cup may be placed to one side with the

[6] See also Csibra & Gergely, 2007.

intention of tidying up, but also with the intention of bringing it closer so as to finish drinking the tea in it. In general, the way in which the action MNS hypothesis explains the attribution of intention to observed agents appeals to typical behaviour by way of the notion of a logically-related motor act. Yet, a motor act is typical or logically related to some other only when viewed as part of an overall, i.e., prior intention. Borg thus concludes (2007, p. 16):

> What one is likely to do next depends not just on features of the context and the initial act in that context but on the complex network of one's beliefs and desires. Yet this fact threatens to render the proposed explanation circular: the revised MN hypothesis seeks to attribute mental states to agents via an appeal to typical behaviour, but one can isolate typical behaviour only in terms of one's attribution of mental states.

Conrado Sinigaglia (2008, 2009) is perhaps the philosopher who has provided the most detailed and persuasive reply to this kind of consideration. In his (2008), he argues directly against Borg's (2007) version of the intentional worry and in favour of the relevance of Iacoboni's and Fogassi's findings. Sinigaglia's main contention is that the intentional worry only appears justified because we remain attached to a far too mentalistic notion of understanding intentions. Yet, he claims, if we viewed the understanding of intentions that the MNS provides in terms of motor aboutness, i.e., in terms of the motor act's goal-relatedness, the worry would fade away. Sinigaglia is quite explicit about this point in his (2009, p. 319) when he claims:

> Quite apart from being the outcome of whatever prior belief and desire I had, my act of grasping, like every other basic motor act, is defined by its own motor goal-relatedness that makes the coherent composition of the various movements to be executed possible, enabling me to control them. It is such motor goal-relatedness that allows someone else to immediately understand what I am doing (and maybe why I am doing it), i.e. to immediately recognize that the movements of my hand are something more than mere bodily movements, that is, that they are part of a specific motor act (or a specific chain of motor acts), directed toward a certain object (with a certain shape, a certain size, etc.) in a given way (grasping).

Doubtless there are many moves and counter-moves that could be pursued at this point. Especially pressing is the philosophical question of which is the correct level of description for action individuation. But rather than getting submerged in this dialectic, I propose to look at a new and interesting MNS functionality that seems to reinforce Sinigaglia's idea and thereby the central explanatory role that the MNS hypothesis plays in intentional understanding, i.e., understanding of motor goal-relatedness. In what follows, I work with a notion of intention that is close to this idea of motor goal-relatedness (Sinigaglia, 2009). I grant the MNS theorist's claim that those who conceive intention as a propositional attitude which plays a critical role in planning action and in practical reasoning, and is subject to characteristic norms of rationality (see e.g. Bratman, 1987), deploy an unwarranted intellectualism. I thus concede that both proximal goals (e.g., grasping) and distal goals (e.g., grasping for drinking) can be represented at the motor level, without appealing to propositional attitudes.[7] My argument only requires that we appreciate the distinction between motor-act and motor intention, where this latter notion is meant to capture the motor goal-relatedness of a particular motor act.

4. The mirror mechanism for peripersonal space: Understanding action potentiality

The notion of affordance, originally introduced by Gibson (1977), captures the relation between certain environmental features and a subject's abilities to act upon them. So-called *grasping-like affordances* or *micro-affordances* (Ellis & Tacker, 2000) refer, in particular, to the relation between the features of an observed, graspable object and the particular motor abilities that such a potential quality of the object calls for in the observer. Observing a mug, for instance, affords a reaching-to-grasp motor act to an agent with the potential to reach for the mug and grasp it; likewise, the sight of a doorknob affords, according to this view, a reaching-for-pulling motor act to a suitably endowed subject.

There are well-known behavioural experiments that support the idea that the particular features of a graspable object provoke a relevant set of grasping potentialities, even when the subject does not have any intention to act upon the object (Craighero *et al.,* 1999). At the neurological level, fMRI studies show that perceiving a graspable object triggers mirror neurons in the left premotor cortex and the inferior parietal lobule even when no motor act is executed. They also show that the same neural circuits that encode motor acts such as hand–grasping also fire simply

[7] I thank an anonymous referee for pressing me to clarify this issue.

when an appropriately able subject perceives the object-related features that allow or invite those acts (see e.g. Chao & Martin, 2000; Grezes *et al.,* 2003).

In an attempt to reinforce the importance of the MNS in our understanding of intentions and actions, and with the ultimate aim of connecting affordance theory and social cognition, Costantini and Sinigaglia (2012) have recently run some very interesting experiments that focus on object-related affordances. The first step in establishing the desired connection is their re-characterization of the micro-affordance relation as dependent on a further enabling condition; a spatial component defined in terms of the observer's peripersonal space, i.e., the space within reach of the observer's limbs. In one of the crucial experiments that support this redefinition of the micro-affordance notion, they record the electric potential from the first dorsal interosseous and opponens pollicis muscles (the so-called 'motor evoked potential': MEP) following transcranial stimulation of the left primary motor cortex while participants in the experiment observed a 3D room in which a mug rested on a table. The mug was situated either within the participant's peripersonal space (within 30 cm) or in their extrapersonal space—i.e., at least 150 cm away. They found that, when the mug was within the observer's peripersonal space, the MEP amplitude was greater than when the mug was located outside this reachable space. Based on these results, Costantini and Sinigaglia suggest that the grasping affordance depends not only on the constitutive relation between the mug's graspable features and the observer's motor abilities, but also on an additional enabling spatial relation that makes the constitutive relation possible, i.e., the relation captured by the notion of peripersonal space. The graspability of an object, they conclude, depends on its being within an agent's peripersonal space (Costantini & Sinigaglia, 2012, p. 440).

The next question Costantini and Sinigaglia raise is whether the spatial relation that enables grasping-like affordances may be constituted not only by a single individual's peripersonal space, but also by the peripersonal space of an observed agent—again, as long as the motor capacities of observer and observed agent are suitably matched. It is here that the MNS hypothesis becomes relevant to the discussion. Costantini and Sinigaglia refer to experiments involving the recording of single-cell firing patterns in macaque monkeys which show that bimodal neurons in the ventral intraparietal area (VIP) discharge not only when there is visual or tactile stimulation within the peripersonal space of the monkey, but also at the sight of such stimulation within the peripersonal space of another individual facing the monkey—the experimenter (Ishida *et al.,* 2009). The neurons did not discharge when the same visual stimulus was presented outside the monkey's peripersonal space but without the experimenter being present. They exhibited the strongest response when the stimulus was within approximately 30 cm of either body, i.e., within each body's peripersonal space: not when located between 60 and 90 cm from the bodies—i.e., outside both bodies' peripersonal space. This suggests 'the existence of a mirror mechanism mapping the peripersonal space of others onto the observer's own peripersonal space, at least in the visuo-tactile domain' (Costantini & Sinigaglia, 2012, p. 444).

Costantini and Sinigaglia report their own behavioural experiments in which they show that even the presence of an inanimate dummy or avatar (but not just any relevantly similar object, such as a cylinder) prompts a remapping of the observer's own peripersonal space so as to make an object outside the observer's peripersonal space, but within the peripersonal space of the avatar, "ready-to-hand". They claim: '[o]ur proposal is that the extension of the space constraint of the affordance relation from an individual to another one is likely to be due to a space mirror mechanism that allows the individual to match others' surrounding space with her own peripersonal space, thus mapping others' action potentialities onto her own motor abilities' (Costantini & Sinigaglia, 2012, p. 445). What is most interesting about these experiments is the suggestion that an observer need not witness the execution of any particular motor act in order to map the observed agent's action potentialities onto their own. 'Our study' Costantini and Sinigaglia (2012, p. 449) contend, 'clearly indicates that there is no need for the participants to be witnessing an action performed by someone else in order to map the surrounding space of another individual onto their own peripersonal space. The space mirror mechanism is motor in nature because of the motor and action-dependent nature of peripersonal space itself.' The idea is that, in the same way as the mirror mechanism for *action* reproduces off-line the motor behaviour of an observed agent, the mirror mechanism for the peripersonal *space* reproduces off-line the set of potential actions afforded by an object situated in the observed agent's peripersonal space. Their suggestion is that such a space mirror mechanism (Costantini & Sinigaglia, 2012, p. 450):

> allows one to grasp another body as a set of motor potentialities that are actually ready-to-hand, whose range and effectiveness are dependent on and strictly intertwined with their own reachable space.

Costantini and Sinigaglia (*Ibid.,* p. 450) thus conclude: 'If all of this is right, the mirror mechanism for the peripersonal space appears to bridge the gap between the motor-based affordance perception and the mirror-based action understanding, playing a key role in understanding *from the inside* what another individual is really doing.'

5. Pre-wired motor chain organization and space mirror mechanism: The first horn of a dilemma

As we have just seen, the main attraction of the *space* mirror mechanism is that its functionality seems to endow an observer with an understanding, or perhaps pre-comprehension, of an observed agent's range of potential actions in the absence of any motor act. In Costantini and Sinigaglia's own words (2012, p. 450):

> Below and before the effective execution of an action by another individual, the mirror mechanism for the peripersonal space unveils the space of actions that are really possible for that individual given a certain situation, providing the observer with an immediate pre-comprehension of the effective realm of her own agency as well as of what she could really do.

Now, thus portrayed, the space mirror hypothesis seems to be open to a rather straightforward objection. The firing patterns of logically-related neurons can be interpreted as providing direct understanding of motor actions only because they code for sequences of motor acts that typically follow an observed motor act in a certain context and thereby determine the motor goal-relatedness of that initial motor act, i.e., its motor intention. Similarly, the function of the *space* mirror mechanism can be interpreted as providing direct understanding of motor action potentiality only if we assume that there are typical motor acts that an object affords. Now, it has long been known that, in addition to mirror neurons, a group of cells known as "canonical neurons" not only respond to motor act execution, but also code for sensorimotor information; they respond to the observation of objects which afford certain motor acts. Canonical neurons are visuo–motor neurons located in the ventral premotor cortex (area F5, close to the mirror neurons). They are active both in the execution of motor acts and in sensory responses to the size, shape and orientation of objects which are not acted upon; they respond to object affordances. Canonical neurons code for, e.g., specific grips given the size and shape of an observed object (see e.g. Sakata *et al.*, 1995). Once the space mirror functionality is incorporated to account for *shared* object-related affordances, its role can only be taken to be the transformation of such visuo-motor information regarding the perceived object into *typically* afforded motor acts. What is thereby understood can thus only be described at the level of motor act behaviour (e.g., grasping) not at the required level of motor intention (e.g., grasping for drinking)—required, that is, to justify the claim that space mirroring activation accounts for 'a preliminary understanding of what others could do given that situation' (Costantini and Sinigaglia, 2012, p. 451).[8]

There thus seems to be a tension between what is taken to be the right level of action individuation within the action mirror hypothesis and what is taken to be the right level of (potential) action individuation within the space mirror hypothesis. To best appreciate this aspect of the problem, let us focus on the following quote from Sinigaglia in which he considers the activation of logically-related mirror neurons (2008, p. 84 emphasis added):

> Whether their activation reflects the goal-relatedness of an individual motor act or is modulated by the overall goal that identifies the action of which the individual motor act is a part, *depends on their motor properties, more than on their mirror properties*, on whether they are organized in motor chains in which each single act is coded within a specific hierarchy of goals. In other words, it is due to this motor chain organization that grasping is not just grasping for grasping's sake, but is a grasping to carry food to the mouth and eat, or a grasping-to-move X from A to B, etc., both when the actions are done by the agent him/herself and when the agent observes someone else performing the actions.

[8] Despite their focus on shared object-related affordances, Costantini and Sinigaglia often, as in the quote above, seem to be arguing for the *general* claim that the space mirror mechanism is the first step in the motor representation of what an observed agent is really doing, inasmuch as it provides the observer with a motor representation of the potential for action that a given situation affords. Yet, this does not seem to be the case for all kinds of motor acts; it does not seem to be plausible in the case of intransitive motor acts, and in the case of communicative motor acts in particular. Many intransitive motor acts, by their very nature, consist of *unpredictable* movements. With regard to *intransitive* motor acts, it is difficult to see what the role of the postulated space mirror mechanism might be. I thank an anonymous referee for bringing this to my attention.

As I hope Section 1 and the preceding quote make clear, the role of pre-wired motor chain organization is crucial in warranting the claim that action mirroring activation provides an understanding of what a witnessed agent is doing—an understanding of the motor goal-relatedness of a specific motor act. It goes without saying, of course, that nothing can be logically related to a motor act that has not been executed. So, all the space mirror theorist would be entitled to claim, in such situations, is that the generated representations would endow the observer with an understanding of potential motor acts. Yet, motor acts without motor goal-relatedness fail to establish, by the mirror theorist's own lights, the observed agents' motor intentions—they fail to individuate motor actions. Hence what the observed agent can *do* remains underdetermined, and no proper understanding of action potentiality is gained.

Furthermore, in cases of overt goal-related action observation, it would be the function of logically-related neurons, as per the MNS *action* hypothesis, to code for the overall intention with which the act was executed—to individuate what the agent is doing. Yet, in such cases, the functionality of the *space* mirror mechanism would be overshadowed by the functionality of the *action* mirror mechanism, as it is difficult to see how coding for object-related shared affordances at the level of motor act potentiality, i.e., grasping, could add anything to an already fixed understanding of motor intentions, i.e., grasping-for-drinking, courtesy of logically-related motor chains.

Alternatively, it could be argued that shared affordances help identify overall intentions in virtue of their bringing out unique and relevant perceptual background information that causes—in the observer—the firing of preferential paths of statistically frequent actions that a given object affords in a given context. Yet, this kind of reply would jeopardize the view of the MNS as a locus of sensorimotor activation, for it would make *perceptual* representations the explanatory key to our understanding of action potentialities. In fact, a perception-based type of relational representation interestingly labelled "affordance structure" plays an important role in the account of intentional understanding and social cognition provided by Csibra and Gergely (2007). Those psychologists defend the idea of a purely perceptual goal attribution mechanism, which they dub *teleological reasoning*, as an alternative to the MNS hypothesis for explaining the understanding that we seem to have of observed motor behaviour.[9] They take the notion of affordance structure, understood in terms of background information about mutual physical constrains between an actor and a situation, to be part of this perceptual goal attribution mechanism. Where the task is that of understanding the goal of an observed agent's action through observation, they claim (Csibra & Gergely, 2007, p. 72):

> What is required for this task is a causal analysis of the affordance structure of the observed actions and the artifacts they involve in order to recover which elements of those actions (and artifact use) are necessary and sufficient for producing the desired effect.

This would allow us, Csibra and Gergely contend, to determine which feature of the observed action is relevant to understanding the observed agent's overall intention. If Csibra and Gergely are right, the notion of affordance structure calls for a *perceptual* reconstruction of action potentialities, which are thus recognized and interpreted at a higher level of cognitive processing, prior to their being activated as sensorimotor representations. Hence, were we to construe the notion of shared affordances along the same lines as Csibra and Gergely's notion of affordance structure, the advocate of the space mirror mechanism would seem committed to claiming that specific motor mirroring activation depends on shared object-related affordance that is already perceptually interpreted, which would, of course, undermine the central view of MNS activation as essentially motor in nature.

To sum up, *space* mirroring, without a witnessed motor act, would fail to explain understanding of *action* potentiality, unless some prior selection process grounded in perceptual representations is invoked. At the same time, where the witnessed behaviour is of an ordinary goal-related action, the *action* mirror functionality makes any appeal to the *space* mirror functionality superfluous.

[9] Alternative or perhaps complementary, not just to the MNS hypothesis, but also to the action-effect association view, according to which understanding other agents' motor behaviour is based on bidirectional associations between actions and their effect (see e.g. Elsner, 2007). Unlike Cisbra's solo papers (2005, 2007), together in this article the authors seem to suggest that MNS-based explanatory frameworks —what they call *simulation procedures*— may be compatible with their teleological reasoning model of goal attribution.

6. Shared object-related affordances and the explanatory role of the space mirror hypothesis: The second horn of the dilemma

In this final section of the paper, I want to pursue a different strategy; for it could be argued that my criticisms give too much weight to the role of intellectualist theorizing in the way we understand other creatures' potential actions—precisely the role that the space mirror hypotheses aims to challenge. It could furthermore be shown that a more charitable characterization of the hypothesis would locate it within an enactive and embodied view of social cognition and perception—a view that challenges the traditional dichotomy between perception and action, and which may thus help resolve the difficulties encountered in the previous section.

Although Costantini and Sinigaglia (2012) do not explicitly endorse enactivism or embodiedness in order to support their hypothesis, it is clear that the postulated space mirror mechanism fits seamlessly into such a theoretical framework.[10] On the one hand, the idea of affordance naturally belongs to a view of embedded and embodied cognition characterized in terms of the exchange between the physical/biological features of an organism and those of the environment in which the organism is embedded and functioning. The notion of *shared* affordance further emphasizes that the environment can be so complex as to include other agents and the objects within their reach. Such a notion thus distinctly echoes a view of brain–body–world relationships not just as dynamically coupled, but also as extending beyond the agent's skin—one of the central tenets of the view known as *extended cognition* (see e.g. Clark & Chalmers, 1998). On the other hand, the very function of the space mirror mechanism seems to fit well with a sensorimotor, enactive account of perception, according to which perceiving is a form of acting. In contrast to more traditional views of perception, the enactivist holds that perception is constituted by agents' abilities to explore and interact in specific ways with the environment in which they are embedded. The idea, defended among others by Alva Noë (2004), is that to perceive is not to internally register sensory stimuli, but to master certain sensorimotor skills. The mastery of sensorimotor skills, seen as an understanding of the ways in which the appearances of objects change in response to an agent's

[10] Sinigaglia (2009) does explicitly defend the role of MNS within an enactive approach to social cognition.

movements and exploratory behaviour in the world, is taken to be constitutive of perception. This seems to be the relevant context in which to understand properly Costantini and Sinigaglia's claim (2012, p. 449) that: 'the mirror mechanism for the peripersonal space has to be construed as primarily motor in nature.'

By locating the space mirror mechanism for the peripersonal space within this framework, we thus appear to be able to challenge a distinction that seems to drive some of the criticisms raised in the previous section: the distinction between motor simulation and covert action imitation. For, if the representations generated by the space mirror mechanism are taken to be motor in nature, then such representations are best conceived of as the array of sensorimotor skills afforded by particular objects in specific situations—including situations in which the objects are suitably located within the peripersonal space of an observed agent. Thus conceived, such motor representations become much better candidates to contribute to the understanding of action potentiality in observed agents. According to this interpretation of the space mirror hypothesis, when observing another agent whose peripersonal space contains an object, the observer would be able to understand the potential motor acts available to the agent based on an understanding of the sensorimotor contingencies that such an object affords the agent in that particular context. There need not be any specific motor act executed because, on this interpretation, the function of the space mirror mechanism would just be to code for sensorimotor contingencies. It would be the understanding of these sensorimotor contingencies, which the observer makes their own, that enables the observer to understand the observed agent's array of potential acts.

It is important to note that I am hereby granting a notion of motor act which is stripped of any putative intellectualist undertone that the contrasting notion of motor intention may carry, since on the minimalist reading of motor intention adopted in the previous section—a reading that the advocates of the MNS hypothesis endorse—there is no motor intention understanding without motor goal-relatedness understanding. Yet, if this is the correct interpretation of the hypothesis, there does not appear to be any explanatory work left for the *mirroring* in the space mirroring functionality; for the key explanatory notion here is that of shared object-related affordance—a notion that seems to call for neural representations that code not just for the causes of current sensory information, but for the anticipated trajectory of future states. The notion of shared object-related affordance seems to call, in other words, for a view of the brain as a predictive engine rather than as a mirroring engine. Indeed, once Costantini and Sinigaglia's space mirror functionality is located within this enactive view of perception, the alleged understanding of action potentiality in cases where there is no overt motor act seems to be much better accounted for by some version or other of the so-called predictive coding hypothesis—not the space mirror hypothesis.

To even try to summarize what has become one of the most influential views in computational neuroscience goes far beyond the scope of this paper. I will say just enough to justify my suggestion above. One of the main functions of our brain is to enable us to cope successfully with our environment by representing it in such a way as to allow us to execute the most appropriate action at each particular moment. According to the predictive coding hypothesis (see e.g. Bar, 2007; Dayan et al., 1995; Friston, 2009; 2010; Hohwy et al., 2008; Lee and Mumford, 2003; Rao and Ballard, 1999), higher-level cortical processing regions in our brain anticipate what the next perceptual input to a lower-level cortical processing region is going to be. Such predictions are based on information already in place about the structure of the world and how likely it is, given such a higher-level model of the causal structure of the world, that a certain state of affairs will follow the state we are in. High-level predictions are sometimes inaccurate, i.e., the higher-level processing regions of the brain make predictive errors and have therefore to adjust so as to lessen the disagreement between the prediction and the lower-level input. In doing so, however, they encode a very detailed and large amount of information about the source of the perceptual signals that reach the lower-level cortical regions, i.e., about the world. The brain is treated, in accordance with this view, as a giant Bayesian engine always trying to predict the next perceptual state based on a constant and coupled flow of information between different hierarchical processing regions and input signals.

The predictive coding hypothesis thus challenges the traditional account of visual processing as consisting of the feedforward channelling of information from lower-level to higher-level visual areas, with the information finally analysed at the highest levels. Instead, the hypothesis depicts our perceptual understanding of the world as driven by top–down predictions, which nevertheless are a response to constant bottom–up input signals. The resulting picture is one in which there is a constant and dynamic coupling of sensory and motor representations, with the higher-level cortical regions constantly hypothesizing what the next input to the lower-level regions is going to be, i.e., constantly hypothesizing about potentiality; the perfect framework for a notion such as that of shared object-related affordance. For it is potentiality—action potentiality in particular—that the higher-order cortical processing regions seem to have evolved to capture. When I witness an agent with a suitably located object in their peripersonal space, my brain is already busy anticipating what the next perceptual state is going to be, given the information available, and in doing so, it yields a representation of the array of motor acts that both the observed agent and I could engage in. Generalized predictive coding, like the enactive and sensorimotor view of perception, brings in a circular causality that makes the traditional boundary between sensory and motor representations disappear. It thus seems to be the optimal view of neural representations to be exploited in the theoretical treatment of shared object-related affordances. Yet, within such a theoretical treatment, the space mirroring functionality does not appear to play any significant role.

It may thus very well be that the notion of shared object-related affordance brings with it a much needed revision of the standard dichotomy between motor and non-motor representational states. It may also be that, once the representations allegedly generated by the space mirror mechanism are given an enactive, embodied and extended interpretation, the space mirror hypothesis does not have to face the problem of potential action underdetermination highlighted in the previous section. However, the space mirror advocate faces, on this more charitable interpretation of their view, a different, but equally difficult problem. For, if understanding of the potential motor acts that an object affords an observed agent is achieved through the sensorimotor representations generated by shared object-related affordances, all the explanatory work seems to be done by the enactive dynamics of the representations of such an affordance structure—not the mirroring functionality itself. Furthermore, on this interpretation, the enactive dynamics of the affordance structure plays the role of prior expectations for recognizing sensorimotor trajectories, and it thus seems to be much better suited to an account of sequential motor prediction akin to the account offered by the predictive coding hypothesis.

The dilemma for the space mirror advocate is thus clear. On the one hand, should motor intention be required for action understanding, as per the action MNS hypothesis, the space mirror hypothesis would fall short of explaining understanding of *action* potentiality, as there is no motor intention without motor act goal-relatedness. On the other hand, if it is just understanding of potential motor acts that the space mirror hypothesis accounts for (and key in such understanding is the enactive and sensorimotor nature of the representations generated by shared object-related affordances) then, not only does the hypothesis seem to fail to do any real explanatory work, but there is an alternative account that appears to be much better suited to the task.

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