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Mirror neurons as a conceptual mechanism?

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Abstract The functional role of mirror neurons has been assessed in many different ways. They have been regarded, *inter alia*, as the core mechanism of mind reading, the mechanism of language understanding, the mechanism of imitation. In this paper we will discuss the thesis according to which MNs are a conceptual mechanism. This hypothesis is attractive since it could accommodate in an apparently simple way all the above-mentioned interpretations. We shall take into consideration some reasons suggesting the conceptualist characterization of MNs, as well as some possible replies. We shall figure out how an argument for the conceptualist hypothesis could be deployed, focusing on the notion of *off-line* processes, which turns out to be the crucial (and maybe problematic for mirror processes) property necessary to ascribe concept possession. Our conclusion will be that, despite of there being some evidence for the conceptualist account, the issue cannot be definitely settled, because there are both experimental shortages and conceptual difficulties. In particular, there are (at least) three distinct senses in which MNs can be regarded as a conceptual mechanism, but we shall argue that only one of these interpretations can be defended.

Keywords Concepts · Mirror neurons · Off-line process · Categorisation

This is a fully co-authored paper. Both the authors are jointly responsible for each section.

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1 Introduction

Originally discovered in the pre-motor cortex of macaques' brains, mirror neurons (MNs) discharge not only when the animal performs an action, but also when it perceives similar actions being performed by another individual, typically a co-specific or a human being (Di Pellegrino et al. 1992; see Rizzolatti and Sinigaglia 2010 for recent data supporting the hypothesis of a parieto-frontal mirror circuit). Clusters of cells with mirror properties have been also discovered in human beings, in the pre-motor cortex and in other regions of the brain as well (see Rizzolatti and Sinigaglia 2007, 2010).

The functional role of MNs has been assessed in many different ways. They have been regarded, *inter alia*, as the core mechanism of mind-reading (in the context of simulative theories of mind-reading, see Gallese and Goldman 1998), the mechanism of language understanding (simulative theories of understanding, see Gallese and Lakoff 2005), the mechanism of imitation (see Iacoboni et al. 1999; Rizzolatti et al. 2001), not to mention some more audacious claims that we shall not discuss here.

These interpretations should not be regarded as mutually exclusive. Indeed there is at least one common feature that they all share, a point on which everybody agrees, namely, that MN activity is the mechanism whereby *motor intentions* are recognised. The idea is that we understand, at least in the sense of having a sort of pre-rational grasp or insight, what an agent is doing (for instance, grasping an object) by replicating, to a certain extent (without executing it), her motor behaviour. This is what is usually meant by the expression 'mirroring'.

Our aim in this paper is to discuss the thesis that MNs *are a conceptual mechanism*¹. We shall take into consideration some reasons suggesting the conceptualist characterisation of MNs, as well as some possible replies. We shall figure out how an argument for the conceptualist hypothesis could be deployed.

Our conclusion will be that, in spite of there being some evidence for a conceptualist account, the issue cannot be definitely settled, because there are both experimental shortcomings and conceptual difficulties. The structure of the article is the following. In section "2" we recall those properties of MNs that are most relevant to the conceptualist hypothesis, so as to pave the way for the discussion. In Sect. "3" we put forward some initial reasons to suppose that MN activity is a conceptual mechanism. In Sect. "4" we sketch how a more robust argument for the conceptualist hypothesis could be mounted, based on the idea of specifying a particular requirement on the notion of a concept, i.e., the off-line processing mode. Finally, in Sect. "5" we show that there are three distinct senses in which MNs can be regarded as a conceptual mechanism, but we argue that only one of these interpretations can be defended.

¹ This thesis is clearly consistent with the above-mentioned claim that MN allow to recognise motor intentions.

2 Paving the way: three relevant claims

Since probably every reader already knows what MNs are, we shall restrict ourselves to recalling some properties and statements that are particularly relevant to the present discussion.

(1) *The tuning-fork hypothesis*. According to Gallese et al. (2004, p. 396), MNs activity allows “a direct experiential grasp of the mind of others”, a pre-conceptual apprehension of another person’s psychological point of view. Instead of inferring another person’s mental states from perceptual evidence we ground our social knowledge on a sort of empathic resonance made possible by MN activity. Following Saxe (2005) and Jacob (2009a), we will refer to this interpretation as the ‘tuning-fork model of human social cognition’.

(2) *Congruence* between the observed and the executed action (Csibra 2007). A minority of MNs is *strictly* congruent, i.e., they are activated when the agent performs an action and also when he perceives someone else’s action, but only if the observed behaviour is constituted by movements almost identical to the movements involved in the performed action. For example, they fire when someone grasps a peanut with a precision grip and also when he sees someone else grasp a peanut using the same kind of precision grip. On the contrary, most MNs are *broadly* congruent, i.e., they are activated even if the perceived action is not physically identical to the executed action. For example, broadly congruent MNs fire when someone grasps a peanut with a precision grip and also when he sees someone else grasping a peanut with other types of grip, or even with his mouth (for an analysis of congruence see, e.g., Ferrari et al. 2003). Among broadly congruent MNs are the so-called “logically related” MNs (see sect. 3) and the neurons described in the following point.

(3) *Multimodality*. About 15 % of MNs that fire when a monkey performs a noisy action (such as breaking a peanut) are also activated when the animal observes or hears the same action performed by another agent (Kohler 2001; Kohler et al. 2002).

3 The conceptualist hypothesis

In early interpretations, MNs were usually regarded as a non-conceptual or pre-conceptual mechanism. The above-mentioned tuning-fork hypothesis is a good instance of this view. More generally, to put it in a nutshell, the theoretical background of MNs is based on the idea that cognition is a sort of sensorimotor know-how. It is in this spirit that Rizzolatti et al. (1988) talked about a motor vocabulary made available by MNs: there is a repertoire (in mirror areas) of motor acts and we grasp a movement by matching the perceived movement to the appropriate act of the repertoire. More recently, however, some authors, including MNs scientists, have suggested that MNs can better be assessed as a conceptual mechanism.

Although most authors stressed the fact that, when an observer interprets an agent’s behaviour, there are MNs that are simultaneously active in *both* brains, Jacob (2008, 2009b) points out that mirroring could also be described by saying that

the same population of MNs fire at different times in *one* and the same brain. In fact one and the same group of MNs is activated in the brain of one and the same person when he perceives and when he acts. This remark is the starting point of the conceptualist hypothesis: as Sperber (2005) was the first to argue, a brain mechanism being active both when an agent performs an action and when the same agent, on different occasions, perceives the same kind of action performed by another, realises the kind of informational *integration* that is characteristic of conceptual mechanisms. The idea is that the organism recognises two different instances of an action as being the same action, independently of which system performs it. Quoting Sperber (2005), “Realising the concept of an action that the macaque can itself perform, it integrates not two perceptual presentations of the action, but visual perception and information from the motor control side”. This is exactly what MNs allow us to do: the same cell that fires in my brain at time *T* when I grasp an apple with my hand also fires at time *W* when I see Jane grasp an apple with her hand.

Sperber’s suggestion has been worked out by Jacob (2009b), who tried to find further experimental evidence for the conceptualist hypothesis. As we have seen, most MNs are only *broadly* congruent (see Ferrari et al. 2003): they discharge both when an action is performed and when the same action is perceived, even if the movements involved in the two actions—the executed one and the perceived one—are different. Now, a mechanism which recognises that two superficially different behaviours share some deeper similarities is—according to Jacob—a conceptual mechanism. The mechanism is in fact able to *abstract* from some (shallow) differences to focus on certain similarities; and abstraction is certainly a mark of categorisation, which is the core function of concepts.

Therefore MNs seem to exhibit two distinctive features of concepts: integration and abstraction (arguably, these two features are two sides of the same coin: in order to integrate two sensory modalities, information must be abstracted from the sensory informational flow).

Another reason to suppose that MNs are a conceptual mechanism is offered by the case of “logically related MNs”. In this context we are referring to a class of neurons found in a study carried out on humans by Iacoboni et al. (2005), but it is fair to point out that a population of logically related MNs was already described in monkeys’ F5 area by Di Pellegrino et al. (1992); see also Rizzolatti et al. (1996), though at the time their functional role was not worked out.

Following the interesting single-neuron study realised with monkeys by Fogassi et al. (2005), Iacoboni and colleagues carried on an experiment with human beings using functional magnetic resonance (fMRI). They showed some video-clips containing three different pairs of situations: *actions* without context (grasping a cup with a precision *vs.* whole hand grip), possible contexts with no action (scenes containing objects), and actions in a context (grasping actions in contexts suggesting drinking tea and cleaning up after tea). Crucially, the authors referred to this latter condition as the ‘*intention*’ condition, as it suggests two different *prior* intentions. While there is a unique motor intention common to both acts (grasping the mug), the prior intention—i.e., the goal underlying purely motor intentions—is presumably different in the two contexts (drinking *vs.* cleaning).

The strongest activation in the right inferior frontal lobe –a brain area containing many MNs– was obtained in the intention condition. Moreover, within the intention condition, the activation was stronger for the tea-drinking situation, that is, for the most common and natural action we make with such a container.

In the authors' interpretation, these findings “strongly suggest that coding the intention associated with the actions of others is based on the activation of a neuronal chain formed by mirror neurons coding the observed motor act and by ‘logically related’ mirror neurons coding the motor acts that are most likely to follow the observed one, in a given context” (p. 5). Therefore, the authors' claim is that logically related MNs code the *prior* intention, i.e., the causal antecedent of motor intention.

Now, if there are neurons that discharge both when an action (e.g., grasping) is perceived and when a different, *causally related*, action (e.g., drinking) is executed—these are what ‘logically related mirror neurons’ do—then one could suspect that MNs are an inferential mechanism, as pointed out by Jacob (2007): “For better or worse, this view of a chain organization makes the activity of MNs similar to that of systems of classical inference in cognitive sciences” (p. 307). Thus, to the extent that the ability to make inferences is usually regarded as a mark of the conceptual, logically related mirror neurons would implement a conceptual mechanism.

To say that MNs realise sensorimotor concepts on the basis of the mentioned considerations, however, requires considerable clarification. In which sense, exactly, can MNs be said to be a conceptual mechanism? Does the claim that MNs make abstraction and integration amount to saying that MNs are amodal representations? Or are they, rather, modal sensorimotor representations (see e.g. Barsalou 1999's notion of a perceptual symbol)? Or, should MN activity be understood instead as procedural representations, that is, as (part of) motor programs associated with conceptual representations? We shall address these issues in Sects. “4” and “5”.

4 MNs and the Off-line Requirement

Of course, assessing whether MNs are a conceptual mechanism depends on what the requirements are for ascribing concepts. The consensus on this matter is far from being general. There is perhaps agreement only on the following thesis: the core conceptual ability is categorisation, the process by which a natural or artificial system subsumes a stimulus under a class. As Medin and Aguilar (1999) nicely put it, categorisation is ‘the process by which distinct entities are treated as equivalent’.

If this emphasis on categorisation is accepted, whatever pre-theoretical, intuitive notion of concept one accepts, one must account for categorising abilities. Indeed, concepts are in the first instance tools for putting together particulars for a variety of goals: giving appropriate behavioural responses to stimuli of a given kind, forming inductive predictions about properties that have to be applied to new (unmet) particulars, and so on. Therefore, being endowed to a certain extent with the ability to categorise is a necessary and arguably sufficient condition for being able to

conceptualise. However, there are different ways of categorising, or, from a slightly different point of view, categorisation is an ability that comes in several degrees. For instance, certain purely perceptual recognitional mechanisms, based on template matching or Gestalt-like grouping, that allow the subsumption of a stimulus under a class—and that can be attributed to many non-human animals (see *infra*)—can hardly be said to be conceptual (see e.g. Bermudez 1998). Even if, admittedly, it is difficult to get a broad consensus on this matter, there is a kind of (perceptual) recognition which merely involves *nonconceptual* content. So categorisation abilities are distributed along a *continuum*, ranging from very simple discriminative abilities up to language-involving classification. Concepts come into play at some point along this continuum. In order to ascribe genuine conceptual capacities, the use of categories should be flexible and sufficiently sophisticated so that, for instance, the agent is able to perform at least some inferences. In the following subsection we introduce a crucial requirement in order to qualify categorisation as a concept-involving process.

4.1 Off-line mode

As we have argued in a paper on this subject (Meini and Paternoster 2007), there are some reasons to believe that the possession of full-blooded concepts must involve a *flexible* use of mental representations, as opposed to a rigid instantiation of them. We mean by ‘flexibility’ the ability to freely deploy a class-referring mental representation independently of perceptual contingencies.

A good way to account for the overcoming of rigidity is given by the notion of *detachment*, that is, the possibility to cut the link between a stimulus and an associated behaviour. A flexible behaviour can be detached in two senses. First, it must be possible for a system to instantiate a mental representation of something without the relevant stimulus being there, that is, independently of perceptual contingencies. As a consequence, an action can be triggered in the absence of stimulus (as it happens, for instance, when someone thinks he needs to buy some bread, and goes out to buy it). Second, the system must be able to abstain from performing the action usually triggered by a given stimulus or perceptual representation—somehow inhibiting the action.

A system exhibiting a kind of information processing characterised by this double possibility of detachment can be said to work in *off-line* mode.

The off-line modality can thus be defined as the conjunction of the two following features:

1. The ability to activate representations in a top-down manner, without requiring the presence of a stimulus (this is the *input-side detachment* ability)
2. The ability to inhibit, in the face of a given stimulus, the execution of the (complex) action that is normally triggered by that stimulus (this is the *output-side detachment* ability)

This notion of off-line processing should not be confused with the notion discussed by Stich and Nichols (1995). In describing the simulation theory of mind-reading—according to which we understand other people’s minds by putting

ourselves in others' shoes and seeing what would happen in that situation—the authors claim that simulation is carried on by the decision-making mechanism working in a particular modality, i.e., off-line processing. In its “basic”, on-line functioning, a decision-making mechanism, faced with a certain situation, predisposes an action and activates the motor program to perform it (cf. Shallice 1988). In the simulative condition, (according to Stich and Nichols) the decision-making mechanism is triggered by off-line inputs and produces off-line outputs. That is, the same system can be fed by hypothetical or pretend mental states (input-side off-line processing) and does not necessarily trigger the action (output-side off-line processing).

In our framework, the definition of off-line is similar, but is not specifically applied to the decision-making system and does not concern mind-reading. First, we are not committed to the idea that the possession of motor concepts requires running the decision-making mechanism off-line; rather, we are claiming that, in order to be regarded as conceptual, mental representations of (sensorimotor) categories must be deployed in off-line processes: the decision-making mechanism is not involved at all. Second, we are not concerned with the higher-level ability to ascribe meta-concepts, i.e., to represent mental representations; rather, we are only interested in first-order motor concepts.

It is worth pointing out that the off-line requirement in our sense (the relevant sense from now on) does not rule out the possibility that a representation has a perceptual nature and a perceptual origin; rather, what does matter is that the representation is instantiated in the absence of a member of its extension, and without necessarily triggering an action. Our notion of off-line is well exemplified by reasoning, in which mental representations (including non-perceptual ones) can be freely used in the absence of any perceptual stimulus and without producing any action.

Thus it could be argued that off-line processing is the missing requirement for concept attribution, since there is a very strong intuition that rigidity (as assessed here) is incompatible with the possession of conceptual skills. On the one hand, it is hard to deny that the possession of concepts is related to intelligent behaviour, which is characterised by at least a certain degree of flexibility or freedom, i.e., by the possibility of triggering action in a non-rigid way. As we saw earlier, flexibility in this sense can be achieved by the double kind of detachment that constitutes our notion of off-line processing. On the other hand, the ability to act on the basis of unperceived goals seems to be central for conceptual endowment.

It is useful to consider some examples taken from monkey behaviour to better see the difference between on-line and off-line processes, as well as to illustrate the importance of the off-line requirement.

Cheney and Seyfarth (1990) observed a group of vervet monkeys living free in a park. Vervet monkeys, which live in groups of 10–30 individuals, engage in complex vocal interactions. Each individual uses a set of 25–30 signals, which appear to be messages to conspecifics. The most frequent communication contexts are dangerous situations, search for food and sexual interaction. Each of these contexts is characterised by the use of highly specific vocal signals. For instance, three different alarm calls are produced in the face of different predators such as

snakes, birds of prey (usually eagles) and big cats (typically leopards). The monkeys' reaction upon hearing an alarm is also very specific: leopard alarms make vervets run into trees, whereas eagle alarms cause them look up or run into bushes; in response to a snake alarm, vervets keep still and peer at their surroundings.

Note that the escape reaction is not triggered by a unique cause. Indeed, even when it is not alerted by a conspecific alarm, a monkey runs away when it sees a leopard (over and above alarming its conspecifics). Therefore this is a case of multimodal categorisation, as recognition is performed through different sensory channels.

Although the behavioural pattern of vervet monkeys is complex and multifaced, we argue that this kind of categorisation is still too coarse-grained. In fact, the behaviour of vervet monkeys in the face of an alarm is, as described in Cheney and Seyfarth's article, a *rigid* reaction. Whenever a leopard is perceived, the monkey cries and escapes. At the other end of the communication channel, whenever a monkey perceives a leopard alarm, it escapes. That is to say, the stimulus 'leopard alarm' triggers only escape reactions. In this example, animal behaviour is guided by (veridical) perceptual representations that *immediately* trigger the relevant action. To the extent that this temporal constraint is always required, we may conclude that the relevant representations, being 'automatically' triggered by an external event, are (*stricto sensu*) *perceptual*².

This behaviour shows that vervet monkeys are capable of "coarse" categorisation, which is characterised by abstraction and multimodality, while missing the off-line requirement.

4.2 Are MNs an Off-line Mechanism?

If the idea of off-line as a conceptual requirement is convincing, we have now to ask whether MNs are a mechanism that plays a crucial role in our ability to execute off-line tasks³.

At first glance, it might be hard to think of MNs as an off-line mechanism, since they are mere replicators. The kind of computation they perform is, in this sense, rigid: they are constrained by perceptual inputs and automatically trigger a

² This does not imply that monkeys are *definitely* not able to work off-line. Zuberbühler et al. (1999) have shown that Diana monkeys have representations of alarms stocked in long-term memory. Diana monkeys have different alarm calls for two different sources of danger: eagles and leopards. Those alarms appear to be genuinely referential, not only emotional alarms. Indeed, if an eagle alarm call is generated and then a monkey hears a leopard growling, then a leopard alarm is produced. On the contrary, if an eagle shrieks after an eagle call, no further alarm is generated, as monkeys are not surprised by any new relevant information. This 'alarm specifically referring to eagles' persists for at least 5 min. This allows Diana monkeys to 'inhibit' the action ordinarily triggered by the external stimulus, thereby realising what we called 'output-side detachment'. On the other hand, it is hard to establish whether the representation can also be scheduled top-down.

³ It is worth pointing out that, according to our account, the property of being off-line (rather than on-line) is attributed to a global process or ability, that is, to a macro-process individuated at the level of the whole organism. Therefore, when we wonder whether a neural mechanism, such as the activity of MNs, is off-line, what we are asking is really whether the neural mechanism is *used* in a 'global' off-line process. In other words, the off-line rather than on-line character of the neural mechanism is inherited, so to speak, from the corresponding character of the macroprocess or ability.

replicative ('mirroring') response. On the other hand, since (in the case of a *perceived* action) the activation of MNs does not trigger any action, one could say that they realise a sort of output-side detachment. Admittedly, this is a somewhat misleading way of speaking, for MNs do not play an active role in this detachment—they do not *inhibit* the action—rather, the action is not triggered because motor regions are not sufficiently activated (see, e.g., Buccino et al. 2005)⁴. Indeed, mirrored actions seem to be really performed in clinical populations, by patients with prefrontal lesions suffering from imitative behaviour, who cannot but imitate perceived actions (Lhermitte et al. 1986). Be that as it may, the fact that MNs, *qua* motor neurons, are recruited when an action is perceived, does not provide a sufficient reason to regard them as working off-line in observational contexts, since, in light of our definition, the input-side detachment condition is also required, and it is not satisfied in the discussed case. In other words, in the typical cases described in the literature MNs do not work off-line in our sense, since they do not satisfy the requirement of being detached from perceptual stimuli (we shall address this point in the discussion of language understanding in the next subsection).

There could be a different reason, however, to believe that MNs meet the input-side detachment constraint of off-line mechanisms: if, as some authors suppose, they played a role in reasoning, language processing and imagery, then they could thereby be regarded as a genuine off-line working modality, as in this case the mirroring process would be scheduled top-down, in the absence of a perceptual stimulus and without any action being performed.⁵ This would be enough for regarding MNs as an off-line mechanism, since, of course, it is not necessary that they *always* work off-line—they just have to be able to do so in some cases. In this scenario we should further ask whether the role played by MNs is *constitutive*, that is, whether the relevant task is accomplished *in virtue* of their activation. For example, if a reasoning process about a complex action involving motor acts or intentions such as grasping is actually realised by the activation of pre-motor areas—i.e., by the activation of MNs *and* without any mediation of 'central' processes (this satisfies the constituency constraint), then the activation of MNs would clearly be an off-line mechanism: it would be scheduled in the absence of any perceptual contingency (and without triggering any action). On this view, MNs would not be passive executors of an off-line process that starts elsewhere in the brain: rather, their activation would constitute the reasoning. In this case, they would play a crucial role in our ability to perform an off-line task.

We are not yet saying that it *is so*, since, as we shall see below, empirical data for the constitutive role of MNs in reasoning, or imagery, and language understanding are controversial. We are just arguing for a conditional thesis: *if* one wants to argue

⁴ There is no reason for thinking, however, that the output side detachment *must* be based on some inhibition mechanism. It is enough that the loop perception–action should be short-circuited in some way or another.

⁵ It is relatively standard to regard imagery as a kind of reasoning process, at least in spatial domains (see e.g. Johnson-Laird's *Mental Models* and several other authors). Through an imagery process, one is able to draw new information, as, for instance, when one realises that an appropriate combination of a 'J' and a 'D' yields an umbrella.

that MNs are a conceptual mechanism, then one has to show that MN activation is constitutive of such mental processes as reasoning, language understanding or free mental imagery.

In order to check this thesis we shall focus on two cases: (1) language understanding; (2) mental imagery.

4.2.1 The case of language understanding

Prima facie, one could legitimately complain that language understanding is not, according to our own definition of off-line/on-line, a case of an off-line process, since understanding a sentence clearly involves *hearing* the sentence, that is, a stimulus is required. Our reply is that, although the presence of a linguistic stream is of course a necessary condition for activating a comprehension process (otherwise there would be nothing to comprehend), the perceptual processing of the stream is just one step in a complex process, whose semantic or conceptual fulcrum comes later. Understanding the meaning of a word involves grasping (*inter alia*) what its referent is; since the stimulus is a word, not the referent, there is a clear sense in which the process is off-line: grasping the meaning is a process *in absentia*, insofar as it is not required that the referred object be present in the perceptual field. You are on line, so to speak, on a mere linguistic *sound*. In other words, we argue that the linguistic stimulus is just a contingent triggering condition for the understanding process; linguistic processing could perfectly well be scheduled even in the absence of the stimulus, in a top-down way. This is evidenced by the case of language *production* where a linguistic representation is created with no stimulus, in a genuine top-down way. Having stated this point, we are ready to discuss some relevant data.

Recently, some experiments have been taken to show the alleged role of MNs in language understanding. If the suggested interpretation of these experiments is correct, then MNs are constitutively involved in an off-line process, being thus a conceptual mechanism. It is on this basis, *inter alia*, that Gallese and Lakoff (2005) argued for the thesis that concepts (all concepts!—see below) are sensorimotor representations, and that conceptual tasks are performed by MNs.

The relevant experiments concern the comprehension of action verbs: it has been shown that understanding action-referring sentences involves the activation of motor and pre-motor areas (Buccino et al. 2005; Tettamanti et al. 2005; see also Hauk et al. 2004). These experiments are relevant to our discussion since MNs are massively located in pre-motor areas. Let us see in detail what happens in a pair of experiments conducted by Buccino and colleagues.

In the first, the hand or the foot/leg primary motor area⁶ was stimulated by a single-pulse transcranial magnetic stimulation (TMS) while participants were listening to sentences describing hand and foot actions. The stimulation triggers motor-evoked potentials (MEPs) in hand and foot muscles opposed to the stimulated hemisphere. Some sentences contained action verbs [such as '*lavare*' (wash),

⁶ The primary motor area is Brodmann area 4, which is the homolog, or at least the analog, of the F1 area in the macaque brain.

'girare' (turn), 'prendere' (grasp), 'scrivere' (write) etc.]; other sentences, used as control, expressed abstract concepts. Results showed that when subjects listened to hand (/foot)-action-related sentences,⁷ there was an amplitude decrease of the recorded MEPs in the corresponding muscles. In other words, the electrical activity involved in the execution of movement turned out to be partially inhibited, somewhat weakened, when the verb heard matched the muscle involved.

In the second, behavioural, experiment, participants had to respond with the hand or the foot while listening (as before) to sentences expressing hand and foot actions, as compared to abstract sentences. In this case, reaction times were slower when sentences referred to actions consistent with the required response: subjects required to respond with the hand (/foot) were slower when the sentence involved a reference to a hand (/foot) action.

These results can undoubtedly be described by saying that the semantic/conceptual processing of action sentences modulates, directly or indirectly, the activity of the motor system. The second experiment was indeed designed to make sure that the activation of motor areas depended on sentence *understanding*, rather than on a mere reaction to an auditory stimulus. Indeed, only in the second experiment does the task require semantic processing of sentences.

Discounting some minor points still awaiting explanation, what the experiments show from the perspective relevant here is that, to the extent that pre-motor areas contain large clusters of MNs, there are circumstances in which MNs fire in the absence of a perceptual stimulus, i.e., in circumstances in which subjects are not perceiving an action but are just processing *sentences*. Therefore, to put it briefly, MNs seem to be activated when persons are engaged in language comprehension.

Suppose, then, that MNs are activated when people are involved in language comprehension. What does this imply, exactly, for the conceptualist interpretation of MNs? According to Gallese and Lakoff (2005) the experiments show that the activation of a concept is *identical* to the activation of sensorimotor representations. Indeed, when the task requires the subject to process an action concept, a mirror area is activated. Moreover, the activation is somatotopic, i.e., there is a (rough) correspondence between the concept involved in the action sentence and the activated portion of the pre-motor area: if it is the concept of grasping that is involved, then it is the hand-area, i.e., the motor representation of the hand that is activated⁸. This suggests that action concepts are implemented by the activation patterns of MNs in the pre-motor area. To understand, e.g., the concept GRASPING is to activate the motor representation of the action of grasping. To the extent that the concept of an action can be identified with the ability to perform the action as well as to recognise it when performed by other agents, to instantiate the concept of grasping consists in activating the corresponding cluster of MNs in the pre-motor area.

However, it seems to us that Gallese and Lakoff's claim is too strong, in two ways. On the one hand, they take *all* concepts (even abstract ones) to be identical

⁷ To be precise, the TMS was induced simultaneously with the end of the second syllable of the verb (for instance, '*cuci*va la gonna*' ['he was sewing the skirt']), that is, between the root and the suffix.

⁸ Different kinds of movement can be subsumed under one and the same concept. For example, one can grasp something with the hand as well as with the mouth. Therefore the degree of somatotopic organization should be further qualified.

with sensorimotor representations,⁹ whereas the experiments only involve *action* words/concepts. On the other hand, what the experiments show is (at most) that MNs activation is *necessary* to understanding, whereas Gallese and Lakoff seem to imply that it is both necessary and sufficient. Even so, the thesis is extremely important for the conceptualist hypothesis: if MN activation turns out to be necessary for grasping some concepts, it is hard to deny that MNs are a conceptual mechanism.

According to Mahon and Caramazza (2008), however, the reported empirical data do not allow us to discriminate the hypothesis according to which this activation is *necessary* to comprehension from the hypothesis that MNs' firing is merely due to the top-down propagation of activation of cognitive or 'central' areas.

Therefore, it is reasonable to seek further empirical evidence supporting the thesis of the direct activation of MNs ('resonance' to language). It seems to us that there would be a crucial way to falsify the hypothesis that the activation of MNs is necessary and indeed constitutive of understanding: we should selectively impair motor areas and check whether there are, as a consequence, deficits in comprehension. For instance, one could try to inhibit motor areas by TMS during a sentence-understanding task. Actually, a step in this direction has been taken by Meister et al. (2007), who searched for experimental evidence for the thesis that the listener recognises linguistic sounds by simulating—i.e., mentally reproducing—the articulatory gestures performed by the speaker (this is a version of Lieberman's well-known theory). To put it very briefly, they found that the inhibition of pre-motor areas by TMS impairs phoneme-discrimination abilities, leaving intact other perceptual abilities (in the experiment, colour discrimination).

This experiment is not yet what we need, since, though the discrimination of linguistic sounds is of course a requirement for understanding, it has nothing or little to do with *semantic* processing of sentences, which is what is usually meant by comprehension. Therefore, although speech production and recognition are part of the linguistic system—part of what Chomsky has recently called the 'broad language faculty'—, we would not say that this experiment is directly relevant to *understanding*. What it points to, however, is a promising empirical method to confirm or falsify the thesis that understanding an action-referring sentence consists in activating the motor representation of the action (or, as the proponents of this thesis like to say, in *simulating* the execution of action, whence the label of "simulative theory of understanding"). Of course, there are some difficulties in the realisation of these kinds of experiments, including, to begin with, the problem of producing the relevant selective impairments with the TMS method.

Yet, further evidence can be provided by available neuropsychological data from patients affected by motor lesions. Before saying something about these, however, it is worth pointing out that Gallese and Lakoff deny that selective impairments of motor areas necessarily involve deficits in understanding. Why? According to the authors (Gallese and Lakoff 2005, pp. 471–472), the distributed nature of the sensorimotor systems, which extend from frontal to temporal-parietal cortex, makes

⁹ The idea is that the alleged abstract concepts are metaphorical displacements of sensorimotor concepts. See e.g. Lakoff 1987; Lakoff and Johnson 1999.

it very unlikely that a circumscribed lesion is sufficient to yield a deficit. Of course, we must defer to neuroscientists on this point, but, if this is how things stand, the thesis that understanding language is or at least requires MN activation turns out to be not only underdetermined by current empirical data, but also underdetermined in principle. It could not be falsifiable. In fact, not only would we lack the crucial test that would rule out the alternative explanation, but any research based on the assumption that there is a (precise enough) correspondence between motor areas and functions would be put in question, including the experiments that are currently aimed at confirming the “sensorimotor” approach. Experiments like Buccino et al. (2005) are in fact based on the principle of somatotopic organisation.

Taking into account these caveats, the neuropsychological data are, on the whole, promising for the sensorimotor approach. For example, Boulenger et al. (2008) showed that Parkinson's subjects have a selective impairment for action-denoting words (and no impairment for concrete nouns), in the sense that their performances are worse when they have to capture information from a prime¹⁰; and patients affected by the motor neuron degenerative disease (MND) show serious impairments in producing and understanding action verbs relative to nouns (Bak and Hodges 2004; Bak et al. 2001). Notice that these data are, with regard to Gallese and Lakoff's theses, double-edged; on the one hand, they seem to confirm that there is a constitutive relation between the activation of sensorimotor structures and action-verb understanding; but, on the other hand, they seem to show that the thesis cannot be extended to nouns.

Further evidence aiming to suggest that motor areas are directly involved in conceptual tasks is provided by Pazzaglia et al. (2008), who showed that a damage of motor areas in apraxic persons also impairs the recognition of action. Note, however, that these data do not provide evidence for the role of MNs in *language* understanding, even if it is certainly part of the simulative paradigm that understanding an action sentence and understanding a perceived action—understanding the action itself—have much in common¹¹.

In light of this review, it is hard not to take into consideration the hypothesis according to which the activation of pre-motor areas is constitutive of the lexical aspect of language understanding; however, the available evidence is far from being conclusive.

4.2.2 *The case of mental imagery*

If there were evidence that MNs are constitutively involved in freely-deployed imagistic kinds of reasoning, then we could say that MNs are a conceptual mechanism, to the extent that they realise an off-line working mode. As a matter of fact, there is no conspicuous evidence of this kind. However, at least a pair of experiments is worth discussing.

¹⁰ See also Neiningner and Pulvermüller (2003).

¹¹ The same can be said of the data collected in Aziz-Zadeh (2008), who report cases in which motor impairments stemming from ‘anterior’ (frontal) lesions affect action understanding. These data do not test *linguistic* understanding.

Let us introduce, to begin with, the fMRI experiment of Filimon et al. (2007), who focus on the analysis of reaching-without-grasping (rather than grasping) actions. The experiment shows that the same mirror areas are activated by imagined, observed and actually executed actions. The activated areas, to be precise, are the dorsal premotor cortex as well as the superior parietal lobe and the intraparietal sulcus. Notice however that the condition of imagined reaching is peculiar, insofar as the object to be reached is visually presented. Therefore, the relevant imagery process is not, strictly speaking, a case of input side detachment.

A better case is offered by Cattaneo et al. (2009)'s experiment, which shows that imagining a grasping action activates the motor areas that are activated when someone really performs that action. In particular, the activation pattern is the same whether or not the action is transitive, that is, directed to an object to be grasped (contrary to what happens when the action is perceived: in this case, the presence of an object modulates the activation)¹². These results are similar to those obtained by Jeannerod (2001), who showed that motor areas are active even in the absence of overt motion. Were activations proved to be *constitutive* of the relevant processes, they would provide strong reasons to argue for the conceptualist interpretation of MNs. But, again, we are not in a position to definitely assess the issue. Also note that, as in the previously discussed case of language understanding, the experiment does not *prove* that MNs are involved in the relevant processes; this is however a reasonable supposition, as the activation of motor areas requires also the activation of pre-motor areas, which contain large populations of MNs.

Our discussion of a pair of off-line case studies is thus concluded. Before jumping to the conclusion, it is worth to point out that having taken into consideration two distinctive human abilities should not be intended as implying that nonhuman animals do not definitely possess concepts. After all, MNs were firstly discovered in monkeys. However, on our view, the attribution of concepts depends on *how* a representation (or a mechanism) is used, not merely on the kind of representation; therefore it could perfectly make sense to say that one and the same mechanism (the mirror mechanism) is involved in both species, but in the monkey case it is used rigidly whereas in the human case it is used flexibly. It is an open question whether some monkeys are able to work off-line (not in virtue of the involvement of MNs) or even are able to exploit the neuron mechanism in an off-line process (cf. note 2 above).

5 Conclusions: how to make sense of the conceptualist interpretation

We have now all the ingredients necessary to outline some conclusions. A good way to introduce our assessment of the conceptualist hypothesis is the analysis of the functional role of logically related MNs.

¹² In this experiment participants were asked to use/observe/ imagine two different kinds of pliers, requiring two different kinds of movement: normal pliers, which require to close the hand (in order to grasp the object), and reverse pliers, which require to open the hand. These details are not relevant for our point.

Suppose that the activation of logically related MNs is constitutive of an inferential process¹³; in this case Iacoboni and colleagues' data discussed in Sect. 3 seem to show that a simple inductive inference such as *X grasps the cup, therefore X is going to drink* is performed thanks to the activation of motor areas. In other words, we would be able to 'read off' inferences directly from our sensorimotor experience. In this sense, MNs would realise the inference from the concept *grasping a mug* to the (related) concept *drinking*. However, these inferences are on-line, as they are performed *in praesentia* of the perceptual stimulus. Therefore, on the view proposed in this paper, we cannot jump to the conclusion that they implement a conceptual mechanism¹⁴.

As we saw, Jacob (2008) endorses the inferentialist reading of the experiments on logically related MNs, interpreting them as further evidence for the conceptualist hypothesis. Indeed, if MNs realise concepts, then it is not surprising that the observation of an action also triggers an inferential process, whose outcome is the instantiation of another, related concept. However, what Jacob has in mind when talking about the conceptual nature of MNs is quite different from the conceptualist interpretation proposed by Gallese and Lakoff. We have already seen that, according to Jacob, MNs allow to make abstraction. Jacob takes Iacoboni's experiment as further evidence for this: "Arguably, the conceptual representation of the act of grasping is an *abstract* representation that brackets the difference between the purely motor representation and the purely visual representation of the act" (2009, p. 586, emphasis added). Thus, Jacob's idea seems to be that MNs are *amodal* symbols standing for classes of actions, that is to say, they implement action concepts, since abstraction involves having some sort of representation which stands for a *class* of entities, whereas in the former, above-mentioned interpretation the idea is rather that we are able to perform conceptual tasks in a non-symbolic way, by means of our sensorimotor activity.

We saw that both Jacob and Gallese and Lakoff defend a conceptualist hypothesis, though they start from different, indeed rather opposite assumptions. When Gallese and Lakoff argue for the conceptualist interpretation, what they have in mind is that the functional roles usually attributed to concepts can be filled by sensorimotor representations. In other words, concepts are not *amodal* symbols, and, in order to categorise, make inferences, understand language and grasp at least some of one's own thoughts, motor simulation is necessary and sufficient. Concepts can be identified with sensorimotor representations to the extent that the activation of sensorimotor representations allows agents to manifest the above-mentioned cognitive abilities. By contrast, according to Jacob, MNs work as symbols, in the sense that they are *amodal* representations: MNs' patterns of activation can be regarded as the neural bases of *motor* concepts, insofar as they exhibit at least some

¹³ See Csibra (2007) and Jacob (2007) for a discussion of the role of the context in determining the motor intentions subsequent to the perceived action.

¹⁴ Yet, it seems not impossible to conceive an experimental task in which logically-related MNs could be activated *in absentia* of the stimulus, thus realising off-line inferences. Note that we are talking here of *motor* (prior) intention: we are not committed to the thesis that MNs are constitutively involved in determining the prior intention in a *psychological* sense, that is, by doing a sort of mind reading. This is a different issue.

of the typical characteristics of concepts: abstraction, integration, multimodality, and inferential role. When Jacob says that MNs are motor concepts, he means that what MNs do is much more than merely resonating, whereas what MNs scientists mean by saying that MNs are concepts is that resonance, that is, sensorimotor simulation, is just what is required in order to perform conceptual tasks. The latter thesis could have been equally expressed by saying that, far from being abstract, amodal and arbitrary representations, concepts are to be understood as concrete, embodied and modal (sensorimotor) representations. On this view, there are no amodal symbols in the mind at all.

Therefore, we can say that there is substantial disagreement on the nature of cognition behind apparent agreement on the conceptualist hypothesis. This is further highlighted by the different attitude concerning the role of MNs in mind-reading: according to Gallese, MNs are the mechanism allowing mind-reading in the context of the simulation theory of mental state attribution (in Stich & Nichols's sense, see Sect. 4 in this paper). On the other hand, in Jacob's view, the role of simulation in mind-reading is at most ancillary (see e.g. Jacob 2008, 2009a, b).

In the light of the discussion made in the previous section, we would like to propose a sort of intermediate view.

The hypothesis that MNs are a conceptual mechanism can be defended, on our view, by arguing that *motor* concepts are *partly* realised through the direct activation of (pre-)motor areas. Or, more modestly, we argue for the following conditional claim: *if* evidence concerning the constitutive role of MN activation were further corroborated (as explained in the previous section), then MNs would be an important part, i.e., the subjective-motor aspect, of motor concepts: grasping the concept GRASP, for instance, would *require* simulating (through MN activation) the act of grasping.

This account is fairly close to the simulative approach proposed by Barsalou (1999), see espec. Sect. 2.4), to the extent that he identifies concepts with "simulators", that is, mechanisms that activate sensorimotor traits in working memory. There are, however, a few important differences. First, our account is restricted to motor concepts, whereas Barsalou's picture is generalized to all concepts (from this point of view, his view is very similar to Gallese and Lakoff's). Secondly, we are more cautious than Barsalou on the *constitutive* character of motor simulation: as we pointed out above, data on language understanding and imagistic reasoning should be further confirmed. Third, sensorimotor representations *alone* do not exhaust conceptual abilities, since they can hardly allow us to perform certain inferential tasks. Briefly, the reason is that, even if the role of MN activity were actually constitutive, still there would be certain inferences that cannot be performed on the sole basis of motor simulation. Take for instance a semantic inference such as "if X is an instance of grasping, then X is an action [or a gesture]", or "if X is a cloud, then it is not the case that X can be grasped". In these cases, it seems reasonable to say that the activation of a sensorimotor representation is not sufficient to perform the inference. Indeed, inferential relations can be "read off" in the sensorimotor representation only if *every* concept involved in the inference admits of a sensorimotor representation of its own, as happens, for instance, in "if X is an instance of grasping, then ...".

But when the inference involves an abstract or very general concept, such as ACTION, or concerns the limits of the application of a concept (as expressed by negation), then one can hardly see how a sensorimotor representation could do the work. The same is arguably true for the case of metaphorical uses such as “if X grasps a concept, then X has understood something”. In all these cases, the availability of links among symbolic (language-like) representations seems to be not only the most effective, but, indeed, the only way to account for the relevant inferences. True, in the case of motor concepts such as grasping, many—perhaps a vast majority of—inferences can be read off from a sensorimotor representation; nevertheless, as it is highlighted in the mentioned cases, the general thesis that all inferential abilities rest on the activation of sensorimotor representation *alone* can hardly be defended.

Therefore, our thesis is that sensorimotor representations could just be *part* of concepts, and only of *certain* concepts. Though there is a sensorimotor representation associated with, say, *grasp*, this representation does not exhaust our conceptual competence on *grasp* (though it is by far the most important component); and there is no sensorimotor representation associated with, say, *government*.¹⁵ There is more to sensorimotor simulation than mere resonance (as Jacob holds), but, on the other hand, sensorimotor simulation cannot be assimilated to language-like representation.

Indeed, representations coded by MNs are multimodal motor *schemas*: they do not specify an action in every detail, since they abstract from the fine characteristics by which the action is performed. They are not amodal, since information is specified in motor format—indeed they are skeletons of a motor program—but, to the extent that they abstract from the specific features of the movement, they are not purely modal either. They are a sort of intermediate representation between rich and analogue sensorimotor representations and propositional representations.

To sum up, if data showing MN activation in language understanding (or other cognitive tasks) are confirmed, then sensorimotor simulation can be regarded as a form of off-line processing, to the extent that it is not triggered by a perceptual stimulus and does not automatically trigger an action. In other words, if future research offers evidence that MNs play a constitutive role in “high-level” cognition, for example by checking the consequences of the inhibition of motor areas, the conceptualist interpretation of MNs will be confirmed. However, today we must be cautious about this possibility; what we have done in this paper is to clarify what exactly this conceptualist interpretation amounts to, and which constraints are to be specified in order to make sense of it.

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¹⁵ This does not rule out the possibility that pieces of sensorimotor representations are activated during the semantic processing of the word ‘government’. The point is that such activations play no role in understanding.

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