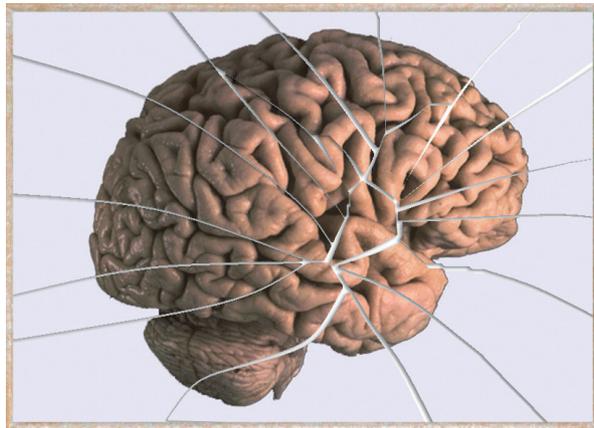


Mirror neurons: still an open question?

Edited by
PAOLO B. PASCOLO



Editorial**□ Mirror neurons: still an open question?**

This edition of Progress in Neuroscience features contributions from scientists involved in the study of mirror neurons and related issues, including:

- Paolo Bartolomeo Pascolo (University of Udine) discusses mirror neurons from a challenging point of view. He argues that, twenty years after the discovery of a specific population of neurons, the mirror neurons, the debate as to their existence is still in full swing. Thus far there is no incontrovertible proof, and the doubts of sceptics have not yet been laid to rest.
- Alessandra Gilardini (BrainFactor) and Marco Mozzoni (University of Milan-Bicocca; BrainFactor Editor) provide a “reflection on mirrors” with a broad review aimed at giving voice to both proponents and doubters of the mirror neuron system.
- Andrea Lavazza (Centro Universitario Internazionale) and Luca Sammiceli (University of Bologna) discuss mirror neurons and free will, exploring the as yet speculative difference between free will in the “ontological” sense and that deriving from a broader “phenomenological” perspective of the perception of intentionality in human actions.
- Mauro Maldonato (University of Basilicata) and Silvia Dell’Orco discuss mirror neurons and the predictive mind, highlighting that our brain is not only a reactive mechanism, capable of providing a rapid response to the stimuli that arrive from the external environment, but is above all a pro-active mechanism that allows us to formulate hypotheses, anticipate the consequences of actions, and generate expectations.

- Daniela Mario (Ca’ Foscari University), after a short overview of the main critiques that are usually applied to neuroscientific explanations, introduces the idea that the mechanism by which specific intentions are ascribed to somebody else could be one of the ways through which mirroring mechanisms are manifest at a phenomenological level.
- Giancarlo Frigato, an independent researcher, speculates on mirror neurons and the eight parallel consciousnesses, enumerating brain areas whose damage causes the loss of consciousness without preventing unconscious perception, and, by delving into neglect analysis, defines a distinction between areas responsible for “access to consciousness” and areas responsible for “real consciousness”.

Autism, empathy and imitation are buzzwords often heard in this context, but any scientific evidence to date is purely indicative, being limited to qualitative evaluation (EMG, functional MRI, transcranial magnetic stimulation, etc.) rather than direct recording from the neurons themselves. This, understandably, leads scientists of the calibre of Csibra, Dinstein and Hickok, among many others, to cast considerable doubts on the consistency of the paradigm, and Pascolo points out that the only works in a position to back up the mirror system theory are those that have conducted direct measurements on simian neurons. However, he is also quick to mention that these, by now rather dated, studies were plagued by several methodological imprecisions *ab origine*, and therefore taking the conclusions they made as read has considerably muddied the waters.

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Indeed, it is important to remember that the mirror neuron hypothesis was based entirely on the inferred behaviour of certain neurons in the monkey and the (subjective) method of “observing” the behaviour of these monkeys in that experimental context. Specifically, when it is said that “the neuron fired both when the monkey observed the action of another grasping a nut and when the monkey performed the action of grasping the nut itself”, Pascolo wonders whether the monkey merely observed the action lying down or whether it was preparing the action. Nobody thought to ask the monkey and so we will never know. However we do know that mirror neurons have never been isolated histologically, and that the task the monkey was set was competitive in nature and involved food. The salivation that a tempting morsel being dangled in front of them will invariably generate in the mouth of an animal could be taken as a sign of desire and even preparation for the act, causing the neuron to fire.

Furthermore, as stated in the article by Paolo Bartolomeo Pascolo and Riccardo Budai⁽⁵⁾, the neuron examined was quicker than the hand of the nut grasper, further indication that the word “observation” used by the research team led by Giacomo Rizzolatti in 1996⁽⁸⁾ should be interpreted with caution. Pascolo and Budai have already criticized the method that led to the enunciation of the existence of mirror neurons in 2008 in an Italian journal (*Rivista Medica*)⁽⁶⁾.

We know that in nature, exchange/confrontation between animals is competitive (for food and territory) and predatory, and this is mediated by understanding of the intention behind the other’s action rather than just comprehension of the action itself. The relationships that would need to develop to understand the action (mirror neuron paradigm) would be fatal for the survival of the species, as the response would be systematically delayed.

However, before we let you get on with reading these contributions and making up your own mind, we would just like to mention the article by Pascolo published in *Biomedical Sciences Instrumentation* (2013)⁽⁴⁾, which discusses the work by Roy Mukamel et al. appeared in 2010 in *Current Biology*⁽³⁾, and an earlier work, also published in *Biomedical Sciences Instrumentation* (2011)⁽⁷⁾, where Pascolo confutes the “measurements” performed on 3-8-day-old macaques by Pier Francesco Ferrari et al. (2008), whose video-clips can be accessed through the *La Repubblica*

website⁽²⁾. Pascolo maintains that in each of the works cited, little weight was given to the synchronization between executor and observer, i.e., between input and output, and this gives rise to several possible interpretations that contrast with the mirror neuron paradigm. Confirming these considerations by Pascolo, we can also mention the contribution by Miia-maaria V. Kujala et al. (2012)⁽¹⁾ regarding the danger in ascribing human meanings to actions performed by other animals, namely that “dog experts’ brains distinguish socially relevant body postures similarly in dogs and humans.”

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Original article**□ Just how consistent is the mirror neuron system paradigm?**

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SUMMARY: *The purpose of this work is to challenge the existence of mirror neurons and the so-called mirror effect by conducting a detailed analysis of some of the experimental measures used on monkeys that led to the formulation of the mirror neuron system paradigm, as well as the non-invasive experiments since performed on humans. It is the Author's conjecture that once the literature often cited in support of mirror neuron theory has been carefully examined, numerous lacunae become evident, which, together with a modest dose of common sense, would seem to cast considerable doubt not only on the science behind the evidence, but also the logic behind the paradigm itself. First and foremost, the experiments carried out by many mirror neuron system theory supporters have been performed in an artificial laboratory context in which the participants were measured for, and ascribed, particular properties that are as yet unverifiable and not yet fully understood. This appears to have opened the door to an "optimistic" interpretation of the data, particularly concerning complex phenomena such as empathy, imitation, etc., that do not yet share unified semantics. Furthermore, techniques used to measure such properties, for instance functional magnetic resonance imaging, suffer from gross limitations, and there are some notable discrepancies in terms of timing, among other things. Hence the results reported so far, and the mirror theory itself, should be treated with extreme caution, and the current trend in applying this hypothesis to real-world treatment protocols, which is currently underway in rehabilitation and autism spectrum disorder should be halted or even reversed until such time as the situation is clarified.*

KEY WORDS: *Action understanding, Autism, Mirror Neuron System.*

□ INTRODUCTION

By 2008, several hundred scientific articles had been published on the subject of mirror neurons (Figure 1) and catalogued in PubMed. Some 20% were written by the Authors of the paradigm itself and associated research teams, and the majority of the remaining 80% were produced by Authors who agree that there is indeed such a thing as the mirror neuron system. However, a large minority of works have been prof-

ferred by MNS sceptics and those who refute the paradigm entirely, and copious literature has been published on the function of neurons, and the brain in general, with no particular focus on the mirror effect^(11,30). Since 2008, scientific output on the topic has greatly increased, but the graph shown in Figure 1 is still a valid representation of the current trend. The articles produced can be classified according to type, and of the many documents considered by the Authors of this paper, more than 20% were reviews.

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LIST OF ACRONYMS AND ABBREVIATIONS: **ASD** = Autism Spectrum Disorder; **BOLD** = Blood Oxygenation Level Dependent; **EEG** = ElectroEncephaloGraphy; **fMRI** = functional Magnetic Resonance Imaging; **MEG** = MagnetoEncephaloGraphy; **MN** = Mirror Neuron; **MNS** = Mirror Neuron System; **PET** = Positron Emission Tomography.

As the graph shows, only 80% consisted of experimental studies and those of a speculative nature, such as some of the articles on language⁽²⁾. There are also some notable studies that predate the formulation of the paradigm^(12,23), and others related to but not directly concerned with the topic^(33,40,54), that need to be taken into consideration if a well-rounded picture of the situation is to be formed.

Leaving aside all the speculative articles and reviews on the subject, the experimental studies can be grouped into two categories: those carried out on monkeys and those, less invasive, performed on humans. As is evident from the graph, the latter far outweigh the former in terms of number, although, at best, they can only provide indirect evidence of the MNS in humans, as their non-invasiveness (fMRI, PET, EEG, etc.) means that they lean heavily on purported similarities between simian and human brains. Although invasive experiments have been performed on monkeys, *PubMed* provides few examples, and instead contains a predominance of speculative studies that merely present reflections on the subject, their arguments being drawn from prior experimental studies or reviews.

Figure 1 shows the pseudo-exponential growth of the literature in question. This is primarily due to the expectations of the scientific community, which no longer feels comfortable with the models of simi-unculus or homunculus, and has leapt at the chance to explore the MNS, apparently a new systematic skeleton key (a new ‘paradigm’ to use the language of Kuhn) able to unlock just about every door, from autism⁽³⁾ to empathy⁽¹⁸⁾, from the understanding and processing of speech⁽⁴²⁾, to sexual preference⁽³⁹⁾, to say nothing of general art interpretation^(17,31), schizophrenia⁽¹⁹⁾, criminality⁽¹⁾, mind reading⁽²²⁾ and “action understanding”⁽⁴⁵⁾, to cite just a few examples.

The cornerstone of all this literature, and the MNS paradigm itself, dates back to a study published in 1992 (di Pellegrino et al.)⁽¹²⁾ in which the Authors report that they have identified neurons in the monkey premotor cortex that discharge both when the animal executes a particular action and when it observes another individual performing the same action. In 1996, following an experimental study by Rizzolatti et al.⁽⁴⁵⁾ the term mirror neurons was coined

to describe these cells, which were ascribed the ability of “action understanding” i.e., to help us “to understand the action of others ‘from the inside’.”

Testament to the popularity of such an appealing idea, rather than seeking to confirm or refute such findings, or those reported by Gallese et al. in 1996⁽²⁰⁾, subsequent experiments on monkeys were designed to open new areas of research^(33,40,54). Thus, the MNS paradigm was created in 1996, and consolidated thanks to continual citations and ample reviews rather than convincing experimental data. Indeed, our *PubMed* search revealed no further works by di Pellegrino et al. on mirror neurons, though their 1992 data is still the touchpaper in the continuing debate on the topic.

Anatomical parallelism between monkey and human brains (F5 and Broca’s area) have favoured experiments designed essentially to translate the paradigm from monkeys to humans by means of non-invasive techniques (EEG, fMRI, etc.), with little effort made to repudiate the original simian findings through hard data (according to Popper’s falsifiability model) or formulate alternative paradigms. It is no mere coincidence that innumerable papers begin with a phrase akin to: ‘Mirror neurons have been discovered in monkey brains...,’ as they merely rehash the original studies. Therefore figure 1 of a review published by *Nature Clinical Practice Neurology* in 2009⁽⁴⁴⁾, echoes that published in previous articles (Rizzolatti et al., *Current Opinion in Neurobiology* 2008⁽⁴³⁾ and Fabbri-Destro et al., *Physiology* 2008⁽¹³⁾), which in turn mimic that published in the original experimental study by di Pellegrino et al.⁽¹²⁾ (their figures 2 and 3). Another loan, figure 2 of Iacoboni et al., *Nature Reviews Neuroscience* 2006⁽²⁷⁾, was borrowed from Rizzolatti et al., *Nature Reviews Neuroscience* 2001⁽⁴⁶⁾, but was first published in *Cognitive Brain Research* in 1996 by Rizzolatti et al.⁽⁴⁵⁾. Similarly, to analyse the content of the paradigm and its various implications, with reference to the interpretative aspects of autism, Rizzolatti et al. (*Nature Clinical Practice Neurology*, 2009)⁽⁴⁴⁾ refer to the study by Cattaneo et al. that appeared in *Proceedings of the National Academy of Sciences of the USA* 2007⁽⁷⁾. In this context, it is also interesting to analyse the paper written by Iacoboni et al. that appeared in *Nature Reviews Neuroscience* 2006⁽²⁷⁾.

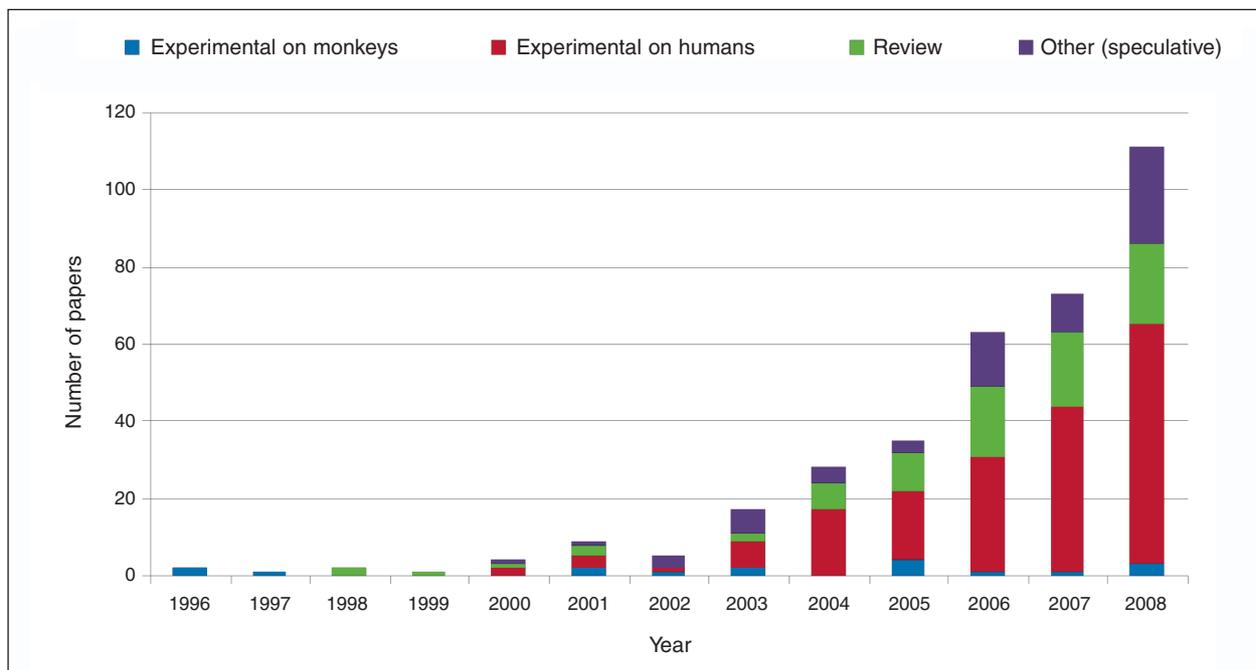


Figure 1. The rising trend in MN literature. The number of papers retrieved from *PubMed* that include the terms: “mirror neuron,” “mirror neurons,” “mirror neuron system” or “mirror system” in their title, abstract or keywords, as a function of the year of publication (since 1996). Note: this exponential trend is still maintained.

It is apparent then, that discussion of the paradigm cannot avoid harking back to the foundation studies, which, as we will see, would benefit from detailed examination. Indeed, although many advanced fMRI studies have been conducted in this field, a large proportion of this research strongly rests on the foundations of the discovery of the MNS in monkeys, taken as incontrovertible fact, which is debatable, and therefore indirectly gives rise to additional elements of doubt^(21,28,38,48). The link that has been forged between experiments on monkeys and those on humans is tenuous to say the least, and the purported existence of mirror neurons in humans is therefore equally shaky. Is the MNS paradigm consistent in the light of fMRI? And, more importantly, is fMRI the right tool for measuring the activity of mirror neurons? Although it should be stressed that an individual who takes part in an fMRI exam does not develop significant movements, such studies require prolonged examination of the area/brain region in question to obtain useful data. Moreover, fMRI involves recording haemodynamics caused by the neural network, which are, at best, indirectly connected to the experiment. Haemodynamic activity caused by the discharge of a few neural elements cannot be sensed with the haemodynamic variation effect of the BOLD signal, which is the

product of variations in the deoxyhaemoglobin concentration in the vasal network, mainly on the prevascular side. In these experiments, electro-neural activity from the cerebral convolution is correlated to the production of a haemodynamic signal that features time delays in the order of seconds and is topographically located in the sulcus between two adjacent convolutions. With reference to Figure 2A, which of the two convolutions is being measured? Figures B and C show the complexity of the ‘network’ in question, a complexity that provides ample opportunity for interference.

Although faint hope seems to be provided by the work of Mukamel et al.⁽³²⁾, based on the detection of neuronal activity on single cells in humans, it appears that the proponents of the MNS theory continue to underestimate the importance of assessing the temporal relationship (delay, during or in advance) between an observed gesture and the neuronal activity of the observer. The MNS experiments carried out using fMRI have been subject to review in *Mirror neurons in humans: consisting or confounding evidence?* by Turella et al.⁽⁵²⁾, which, like others, attempts to test the presumed solidity of the paradigm. This concludes that recent studies based on fMRI adaptation protocol to search for mirror neurons in

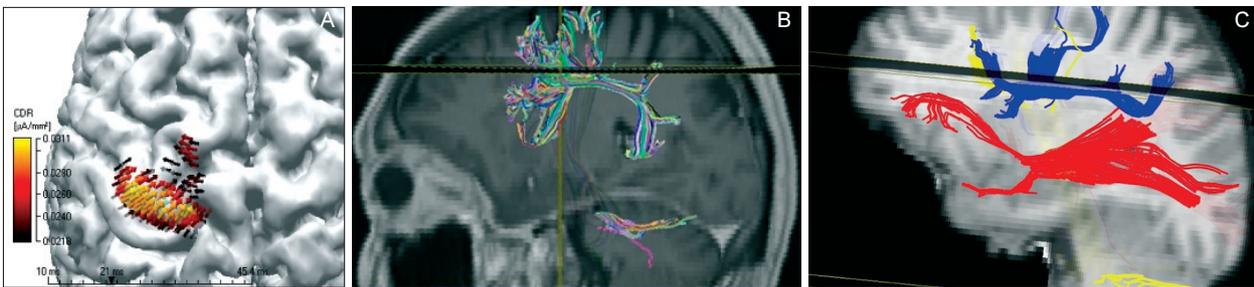


Figure 2. An fMRI study of the human brain. A. Position of the BOLD signal with respect to the convolutions (Examination carried out with Siemens Avanto, fMRI 1.5 Tesla and post-processing with Curry 6.0). B. The cross indicates the exact position of the stimulation electrode obtained during a surgical operation. The image, anatomical and not functional, shows the course of connecting fibres in cerebral white matter. The image was obtained by magnetic resonance. The fractional anisotropy was recorded and then diffusion tensor imaging was performed. The course of the fibres is located (as an MR signal vector that evolves in a specific direction XYZ) between a departure area and an arrival area. According to the direction taken by the fibres, the signal is codified in different colours (green latero-lateral, blue antero-posterior, etc.). C. The colour traces reach the cortex and demonstrate the potential for interference and the complexity of the neural network (*Internal documentation of the Industrial Bioengineering Lab, University of Udine*).

humans have obtained negative or controversial results. Even the representation of results through histograms, obtained as the sum of repeated individual events, without taking into account the characteristics of each individual event (phase, intensity, persistence, etc.), is inadequate, because it cancels out the specificity of each individual neuronal response concerning the phenomenon that is under investigations. Indeed, according to Logothetis⁽²⁹⁾, who also sets out the limitations of fMRI⁽⁹⁾, the prevailing sense is that one should return to examine the initial work, that is, the experiments on monkeys, before proceeding with human experiments^(20,42,53).

These considerations will be discussed in more detail below, in the section: “What was actually seen in the original experiments?”⁽³⁵⁾, in which the Authors start from a paper, published in 2008⁽³⁶⁾ that focused on the analysis of measurements of individual neurons in monkeys, conjecturing that the seminal experiments on monkeys have been given their appropriate weight within the scientific community.

IS THE MIRROR NEURON SYSTEM PARADIGM CONSISTENT IN TERMS OF THE METHODS OF EXECUTING MOTOR ACTIONS?

No one can fail to notice the behaviour typical of an adult in the early stages of educating a child. With a look, the adult gets ready to ‘help’ the child, repeating/following, perhaps mentally anticipating the sequences that the child is expected to carry out. In this situation,

a hypothetical recording of neural activity would doubtless register delayed or synchronized electrical activity triggered by this anticipation (preparation of the motor action) in one individual with respect to the other. It is therefore necessary to examine the motor actions of individuals on an appropriate timescale and, in discussing neural circuits, the study of a hypothetical ‘mirror’ event should provide an examination of every single action, real or ‘virtual’, and of the overall action, with an equally detailed analysis of the times taken to complete these actions.

Boxers are a helpful example to use because all the action takes place within the reach of their arms, and attack and defensive actions, including those involving trunk movement, occur within 200 ms. The boxer on the defensive has to move to ward off his opponent’s fist (note the still arms at time 0 in Figure 3). It is not by mirroring his opponent’s gesture that he is able to avoid the blow - perhaps it is an expression on the opponent’s face or a gesture by his body, the position of his pelvis or his feet, the action he had previously performed, or a combination of all of these and other factors that give the game away, but in any case, he is able to anticipate his opponent’s next move within a very short time frame^(5,36,37). In short, there is no “embodied simulation”, as the process would be too slow to allow a boxer to defend himself. Instead there is a prediction of action-intention of the opponent, stemming from previous experience of tactical and strategic schemes, conferring the ability to anticipate what is coming.

In the case of observed actions, if a mirror effect existed in our brain, “regularities” should be expected,



Figure 3. Reaction times. Boxer action and (anticipated) reaction (A and C still punch, B and D completed actions).

taking place between the experimenter's gesture and the "mirror" neuron firing, with delays compatible to neural circuitry. If, on the other hand, the "virtual" event develops in one's (or a monkey's) neurons in advance with respect to the action proposed by the opponent (or experimenter, for instance in the act of grasping⁽⁶⁾), the activity of such neurons could not reasonably be said to "mirror" the action. Thus, the MNS paradigm would fail. This can be summarized by the schematic reported in the box on the next page. Bearing in mind the works cited in the introduction, it is worthwhile calculating the presumed or assumable temporal phase displacement between the executed action and the observed action. In some cases it is easy to estimate the neuronal timing without using gruesome experiments, as is clear from Figure 6. Let us take another example from the world of sports, i.e., sprinters. Even in the 100 m or 200 m event, their times are fairly analogous to those of boxers. In the "Ready, Set" phase, the runner prepares for action and, as soon as the gunshot is perceived (i.e., a pre-formed neuromuscular chain), starts off in a specific direction (pre-ordered). Reaction times recorded during a representative race for several athletes are: M. Johnson 0.161 s, A. Powell 0.134 s, and U. Bolt 0.165 s. Such values take into account time delays caused by sensory receptors, neural transmission to the cortex, information recognition (in this case the gunshot), neural transmission to muscles, muscle latency and time of muscle activation. The neuron system, in this case of an "audio-motor" effect, starts firing about 30 ms - or perhaps less - after the gunshot, and the "visual-motor" effects have the same delays⁽²⁶⁾. Hence, under experimental conditions, an MN should start firing with a similar time delay following the experimenter's gesture towards the target. Preparation and anticipation are the result of ex-

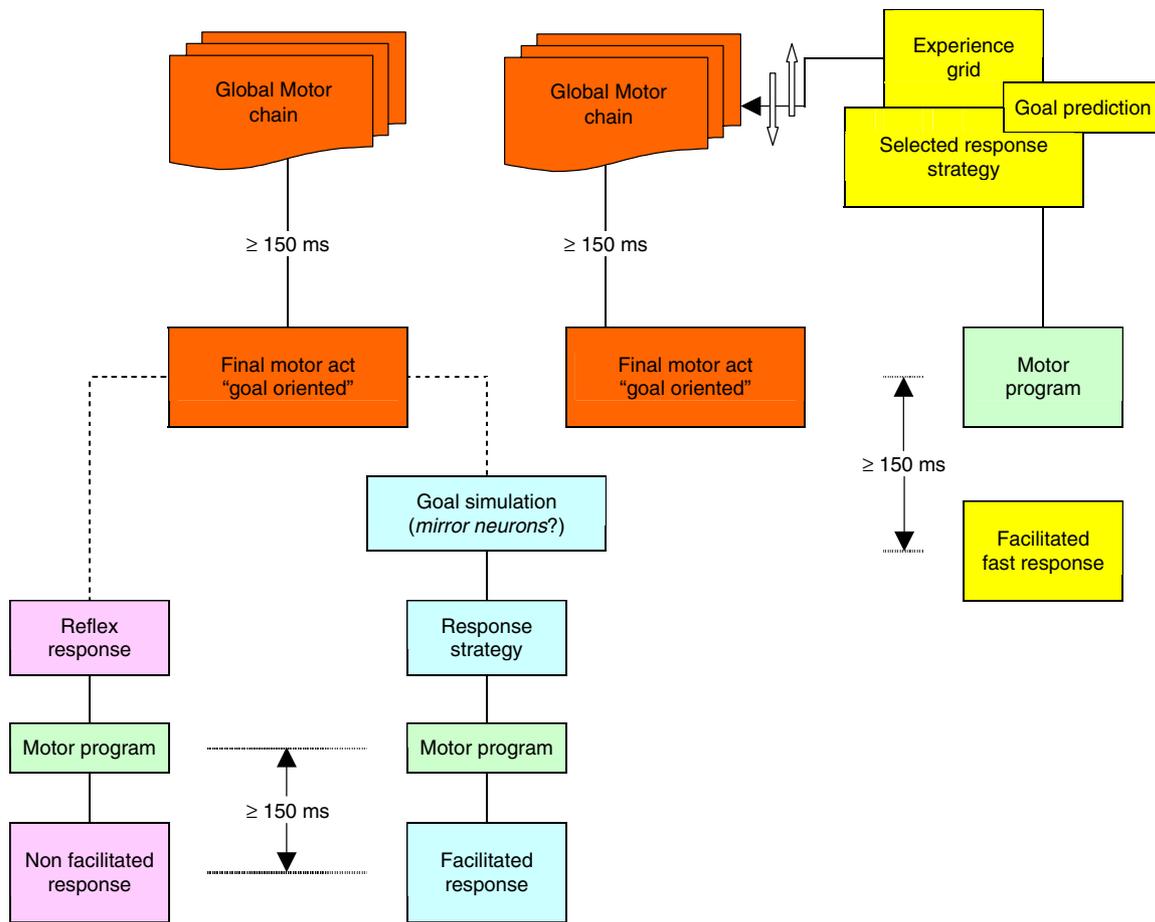
perience, as well as, in the case of competitive events, interpretation of the opponent's movements or expressions linked to the expected event that is yet to occur. If this were not true, only time delays between perceived action and physical reaction, i.e., conventional psycho-technical reaction times, would apply, as the sports person, for instance, would know that they have to perform a certain action but would not know when. In this scenario, a goalkeeper would have little chance of saving a penalty, as reaction times range from 300-350 ms to 600-1000 ms in normal people. However, a good goalkeeper, after studying the characteristics of the penalty taker, will start moving at least 300 ms before the kick. Hence, any possible save is the result of calculation, not of unconscious anticipation.

As previously specified, the experiment recalled in figure 1 of Rizzolatti et al., *Nature Clinical Practice Neurology* 2009⁽⁴⁴⁾ and reported here below in Figure 4, is a foundation upon which all others have been based, in particular those conducted in 1996 by Rizzolatti et al.⁽⁴⁵⁾ and Gallese et al.⁽²⁰⁾. These experiments on monkeys need to be re-examined, and if the measurable times are found to be highly inconsistent, the existence of non-mirror collateral events linked to information elaboration/interpretation, competition for food, "virtual" motion anticipation, etc., should be considered.

□ WHAT WAS ACTUALLY SEEN IN THE ORIGINAL EXPERIMENTS?

To look at these seminal studies more closely, the experiments concerning two neurons, U481 and U483, reported in the 1992 work by di Pellegrino et al.⁽¹²⁾ were analysed. One of these neurons, U483 has

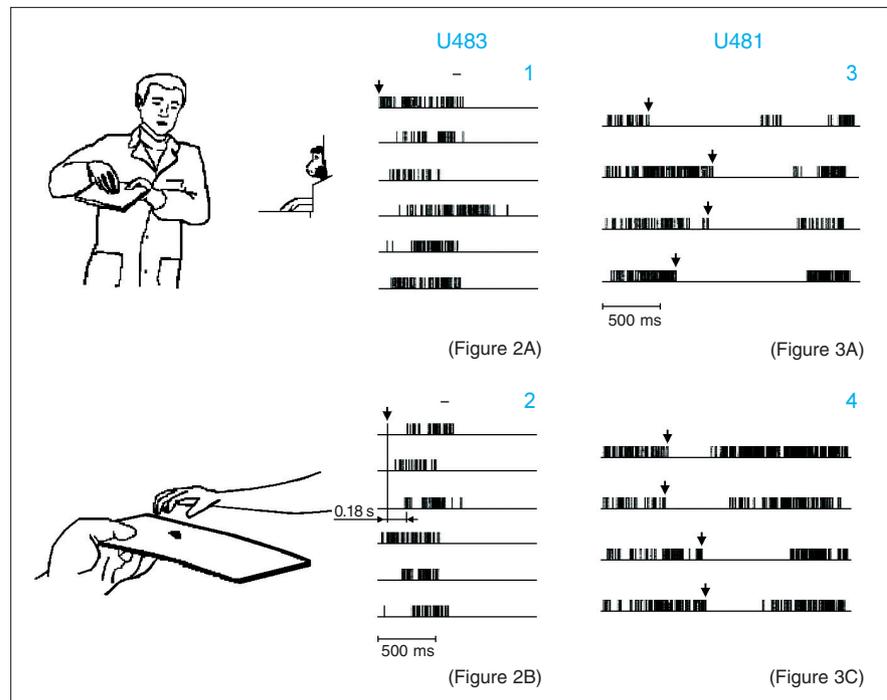
VARIOUS PATTERNS OF RESPONSE TO OBSERVED ACTIONS AND THEIR TIMING



Understanding action means interpreting what another intends to do and being prepared to react accordingly. In a variety of real-life situations, to react appropriately and advantageously, you need to understand the purpose of an observed action well before it develops. It is obvious that the brain of any living organism, when presented with an external trigger, activates mechanisms to interpret the perceived event, but it is also obvious that the brain, geared for survival, provides anticipative dynamics within the “learning-operating” mechanism even between non-cospecific subjects, e.g., a predator studies signs of escape in the prey it is intending to intercept. This signifies assessing/ understanding the intended action of the other by interpreting “precursors” of the action even before it begins to develop (right side of the schematic). To do so it is also clear it will engage the areas of the brain where past experiences that might be useful for the interpretation are stored. This, however, has nothing to do with *embodied simulation* (left side of the schematic), which instead implies, according with the MNS theory, the use of the same neurons^(12,20,45) that are used during execution of an action similar or equivalent to the one observed.

Schilbach⁽⁴⁹⁾ has pointed out that the monkey experiments used to bolster the idea of action understanding were conducted in static and artificial contexts. If you consider the need to understand the action chain (action sequences) and immediately react to the actions of others in cooperative or competitive contexts, but, considering the other as a “second person,” you can see how the supposed embodied-simulation is a weak mechanism⁽²¹⁾, and redundant, if not a hindrance.

Figure 4. Premotor neurons u483 and u481, as described in the article by di Pellegrino et al. (*Exp Brain Res*, 1992)⁽¹²⁾. Examples of a unit selectively discharging: 4.1 and 4.3 as the monkey observes of the grasping movements made by the experimenter (original figure 2A and 3B) 4.2 and 4.4 as the monkey performs grasping movements (original figure 2B and 3C).



also been studied in other experimental works^(13,44). Looking at Figure 4 (left panel), we can see that this neuron starts firing as soon as the experimenter starts to perform the grasping action, then it stops and restarts after the animal itself begins grasping (original figure 2A and 2B of di Pellegrino et al., 1992⁽¹²⁾). If we examine the time delay from the start of the experimenter's action (vertical, black arrow) and the start of firing, this amounts to a minimum of 10-20 ms and a maximum of 170-180 ms. If the former value is consistent with "neurological" times, the latter is consistent with the activity of processing information by the network containing the neuron. Taken as an average, the time delay is 105 ms. The duration of firing during the monkey's observation goes from 0.42 s to 0.98 s, that is the experimenter's moving change in velocity. The animal's firing times during execution range from 0.31 s to 0.5 s.

The neuron labelled U481, whose behaviour in such circumstances is described on the right in Figure 4 (original figure 3A and 3C in Pellegrino et al., 1992⁽¹²⁾), was examined. As we can see, U481 is always active but interrupts its activity, i.e., becomes silent, exactly at the instant of the onset of grasping, either in the experimenter or in the animal. Curiously, there is no delay, not even 1 ms. This neuron, operating in off-on logic "apparently" in phase with the event, was not used as a trigger signal or examined in more detail,

but was nevertheless cited in future works. However, the function of such a neuron is not merely confined to on-off logic, it also provides other information. Furthermore, the work in question⁽¹²⁾ does not report the gesture measurements or the motor acts performed, although an optoelectronic system for kinematic data acquisition (ELITE: ELaboratore di Immagini TEEvisive, TV image processing system, BTS, Garbagnate Milanese, Italy) was used. It is reported that only the animal was wired up. In order to provide a more complete picture, the experimenter's arm should also have been subjected to such recordings, as it provides that which the neuron apparently mirrors (with delays ranging from 20-30 ms). This appears to be a rather large flaw in the method, and was only rectified in later works, albeit not in the same kind of experiments⁽⁵³⁾.

Although some Authors may not feel the need to look for a univocal timing relationship between the gesture observed and the neuronal response, we decided to explore this issue further, focussing our investigations on other seminal experiments. See Figure 5: visual and motor responses of a grasping mirror neuron, a reproduction of both figure 1A from the work of Gallese et al., *Brain* 1996⁽²⁰⁾, and figure 2A from Rizzolatti et al., *Cognitive Brain Research* 1996⁽⁴⁵⁾ (also reported in *Nature Reviews Neuroscience* (2001)⁽⁴⁶⁾ as figure 1A). In these figures, the neuronal

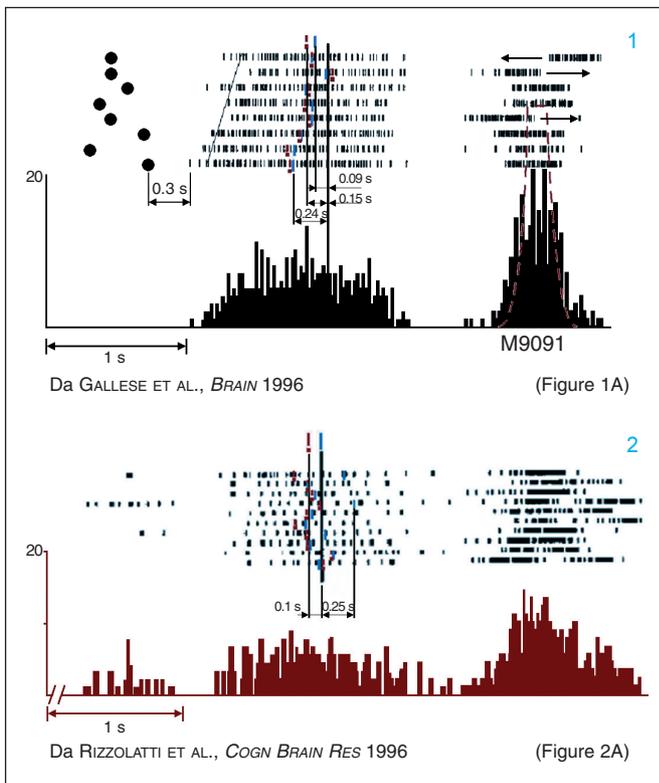


Figure 5. Visual and motor responses of a “grasping” mirror neuron. A tray with food is presented to the monkey, the experimenter grasps a piece of food with his hand and then moves the tray with the food towards the monkey, who makes the grasping movement toward the food. The figures show the action potentials of the neuron recorded over time for each of the actions: the neuron discharges during experimenter and monkey grasping, but in contrast the neuron ceases to fire when the food is presented or moved toward the monkey. In the upper part of the picture (raster plot), the vertical line across is the moment at which the experimenter touches the food; in the lower part of the picture, (histogram) we can see the frequency of the neuron’s instantaneous firing, calculated in intervals (bin) of 20 ms each. The y axes represent spikes/bin and the x axes represent time. The start of the trials is represented by a spot in bold type. Figure 5.1 was taken from figure 1A of Gallese et al., *Brain* 1996⁽²⁰⁾, and Figure 5.2 from figure 2A of Rizzolatti et al., *Cognitive Brain Research* 1996⁽⁴⁵⁾.

activity is measured during the action of food being grasped from a tray.

When the tray with food is offered to the monkey, the neuron does not fire⁽⁴⁵⁾. If it does not fire, we can deduce that the neuron is of the same family/class as the U483 neuron⁽¹²⁾, and should start firing on average around 100 ms from the start of the action, or even 10-30 ms (mirror). This can only occur if the grasping action is begun during the presentation of the tray of food, that is, very quickly (Figure 5). However, in the work it is stated that the presentation of the food on the tray comes first, to show that the neuron does not fire. In Figure 5.1 we can observe the “tendency” (shift) of

the aligning segment - the neuron seems to possess “improving capabilities”. Moreover the neuron in the trial in question (Figure 5), as will be discussed in more detail below, seem to complete the “virtual” precision grip around 0.25 s before the experimenter, that is, the monkey anticipates the experimenter’s actions. Every single recording of the activity relative to the neuron in Figure 5.1 was considered, both in number of firings and in temporal distance between the first and last registered firing, and it was placed in relation with the vertical segment that aligns the achievements of the goal by the experimenter. The median of firings is indicated in red, and the average time in blue. According to these calculations, the global average time and global average firing is anticipated by roughly 100 ms with respect to the alignment segment with a fixed maximum value of about 240 ms, indicating that the neuron had started firing even before the experimenter’s movement. If this is the case, how can it be described as a “mirror”? Indeed, if the neuron anticipates the action, we cannot speak about the “imitation” paradigm. At any rate, the experiment seems to deal with repetitive, rather than improvised behaviour, which would influence or frighten the animal and would, therefore, interfere with the response.

To suggest the validity of using the average as an instrument for measuring the phenomenon in question, and therefore for re-classifying the results of di Pellegrino et al., *Experimental Brain Research* 1992⁽¹²⁾ and Galles et al., *Brain* 1996⁽²⁰⁾, there is a study that records a neuron’s times of activity before, during and after a generic exercise⁽¹⁴⁾. It also

reports a - rather grisly - locking device used on the animals, and the component included in the brain case used as support for the measuring system with microelectrodes (Figure 6).

Moving on to a similar comparison, Figure 7 (a reproduction of both figure 1B from the work of Gallese et al., *Brain* 1996⁽²⁰⁾, and figure 2B from Rizzolatti et al., *Cognitive Brain Research* 1996⁽⁴⁵⁾), it is evident that the signal relative to the first phase of the exercise is relatively weak, perhaps because the exercise was complicated by the use of the pliers to reach the food. The firing times measured on the available data, in the case of the animal’s simple



Figure 6. Experimental Apparatus. Common apparatus used for experiments on monkeys (detail from Fadiga, 2004⁽¹⁴⁾).

observation, goes from a minimum of around 0.2 s to around 1.6 s. We will return to the intensity and quality of the signal found in this part of the experiment later, but for the mean time suffice it to say that the single trials are characterized by irregularities in the positioning of the individual averages. Moreover, Figure 7.1 is incomplete on the right side, making it impossible to determine the firing times of the monkeys' precision grip. Nevertheless the times appear to be substantially greater than those pertaining to the same part of the exercise reported in Figure 5.1.

Among the various experiments documented in Gallese et al., *Brain* 1996⁽²⁰⁾, there is one regarding the execution of the experimenter's precision grip with the food placed on a stylus (a kind of chopstick) rather than in a tray or manipulated with pliers. This picture is not reported here, but in the original the hypothetical mirror neuron shows intense activity but no regularity of firings with respect to the aligning segment (the experimenter reaching the food), with an average delay even as great as 0.5 s. This value suggests additional neural activity of the animal required to understand the complex setting in which the experimenter's gesture takes shape. If mirroring were taking place, this neuron should synchronize with the movement, this being a normal action of grasping food. In short, the first part of exercise 1B should at least reappear in the conclusive trials without showing striking irregularities and delays⁽²⁰⁾.

Further data in the literature support the previous arguments. Take Figure 5.2, which records the response to an exercise identical to that in Fig. 5.1^(20,45). The average time is positioned approximately on the vertical segment,

which indicates the attainment of the target. Once again, the firing average is anticipated with respect to the alignment - two identical experiments but with different averages, that is, only similar behaviours.

The neuron examined Figure 7.2 does not respond in any way to the action of the experimenter holding a pair of pliers⁽⁴⁵⁾. However, in a similar experiment in Figure 7.1 there was a signal detected, and in some of

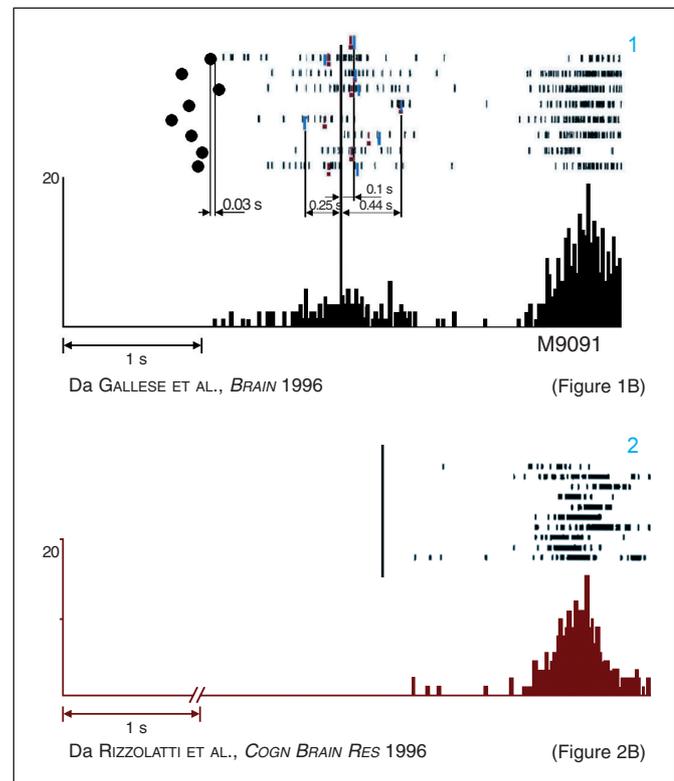


Figure 7. Visual and motor responses of a grasping mirror neuron. The experiment shown is the same as that in Figure 5, except the food is grasped with pliers rather than the hand. Figure 7.1 is taken from figure 1B of Gallese et al., *Brain* 1996⁽²⁰⁾, and Figure 5.2 from figure 2B of Rizzolatti et al., *Cognitive Brain Research* 1996⁽⁴⁵⁾.

the trials it was even strong. The intensity of the firings is greater in the first part of the experiment with the pliers than when the experimenter grasped the food with his hand (Figure 5.2). This being the case, how would the histograms have changed if further trial recordings had been added? Would the same result be illustrated in Rizzolatti et al., *Cognitive Brain Research* 1996⁽⁴⁵⁾, and other subsequent works^{(15)?}

What is more, as Figures 5 and 7 are largely approximate, it is worth making the following observations. The measurements are aligned with the attainment of the target by the experimenter; therefore the histograms that relate to the monkey's grasp are the product of sums of out-of-synch events. The correct histogram for the animal's grip would undoubtedly be different from that shown in the figures - certainly tighter and of greater magnitude. Moreover, on this occasion too, by aligning the experimenters action with the monkey's reaction (see the horizontal arrows in Figure 5.1 and the slope over the histogram on the right), a further difference is generated, both quantitative and qualitative, between the two histograms in Figure 5, the two histograms in Figure 7, and so on.

The control experiments are also worth mentioning. In original figure 11 of Gallese et al., *Brain* 1996⁽²⁰⁾, EMG experiments are reported wherein one mouth and three hand muscles of the monkey were wired up, though no other muscles (for example, the arm), even though the eventual motor action would evolve in a proximo-distal direction. Plus, once again, to study the mirror neuron effect, in addition to the monkey's neuron and forearm, the experimenter should have been monitored in a similar fashion. Once again, in Rizzolatti et al., *Cognitive Brain Research* 1996⁽⁴⁵⁾, the motion analysis system ELITE is discussed and applied to the animal, as in di Pellegrino's study (1992)⁽¹²⁾, but there are still no precise checks of the measurements obtained.

Also somewhat perplexing is the interpretation of the results of the grasp-to-eat and grasp-to-place experiments, shown in figure 2 of the study by Rizzolatti et al., *Nature Clinical Practice Neurology* 2009⁽⁴⁴⁾ retrieved from Fogassi et al. (2005)⁽¹⁶⁾. The statement "this coding implies that when the monkey observes grasping done by another, it is able to predict, on the basis of contextual cues (e.g., repetition, presence of specific objects), what will be in the individuals next motor act. In other words, the monkey is able to understand the intentions behind the observed motor act"⁽⁴⁴⁾, is far from convincing. Is it that the neuron

simply reacts because the monkey sees a different movement, or does it react to the preparation of diverse kinds of actions? This brings to mind the boxer's action shown in our Figure 2, and events connected to the recognition of features or movements (in particular facial), which are dominated by retinal pre-treatment (30 ms according to Honey et al.⁽²⁶⁾). Have the facial expressions of the experimenters been classified or 'masked' to avoid the risk of interference due to visual communication? In this regard it is worthwhile remembering an event in 1907, regarding the comparative biologist and psychologist O. Pfungst and the horse *Clever Hans*⁽⁵⁰⁾, who appeared to know how to answer complex questions. O. Pfungst effectively debunked this myth when he discovered that Clever Hans simply interpreted the gestures of the observer, thereby providing a notable example of methodological paradigm of experimental fallacy.

At this point, harking back to what is written in the introduction, it is useful to note that in Rizzolatti and Sinigaglia, *Mirrors in the brain*, Oxford University Press 2008⁽⁴⁷⁾, some figures (figures 5.9 and 5.10), supposedly representing the brain activity recorded by fMRI in different conditions (humans vs. humans, vs. monkey and vs. dogs), are different to those first reported by Buccino et al. in the *Journal of Cognitive Neuroscience* 2004⁽⁴⁾: some red-yellow areas have been modified, and some areas, specifically the those related to vision, have been made less evident. As a consequence, it may appear to the average reader that they provide better qualitative support for the MNS theory than the original figures (see our Figure 8). These images were meant to illustrate how the comprehension of another subject's motor acts (i.e., the movement of the lips of the observed subject) is high between humans, lower when a human observes a monkey, and very poor when a human observes a dog. In other words the results indicate a monotonically decreasing function, the more the observed subject differs from the observer⁽³⁴⁾. In a previous work⁽³⁶⁾ we expressed our doubts regarding these results, and a recent fMRI study in which "dog experts' brains distinguish socially relevant body postures similarly in dogs and humans" confirms that such doubts are reasonable⁽²⁸⁾.

□ AUTISM AND MOTOR ACTS

MNS theory has been extended to cover conditions such as autism. Although it is a seductive hypothesis⁽²⁴⁾

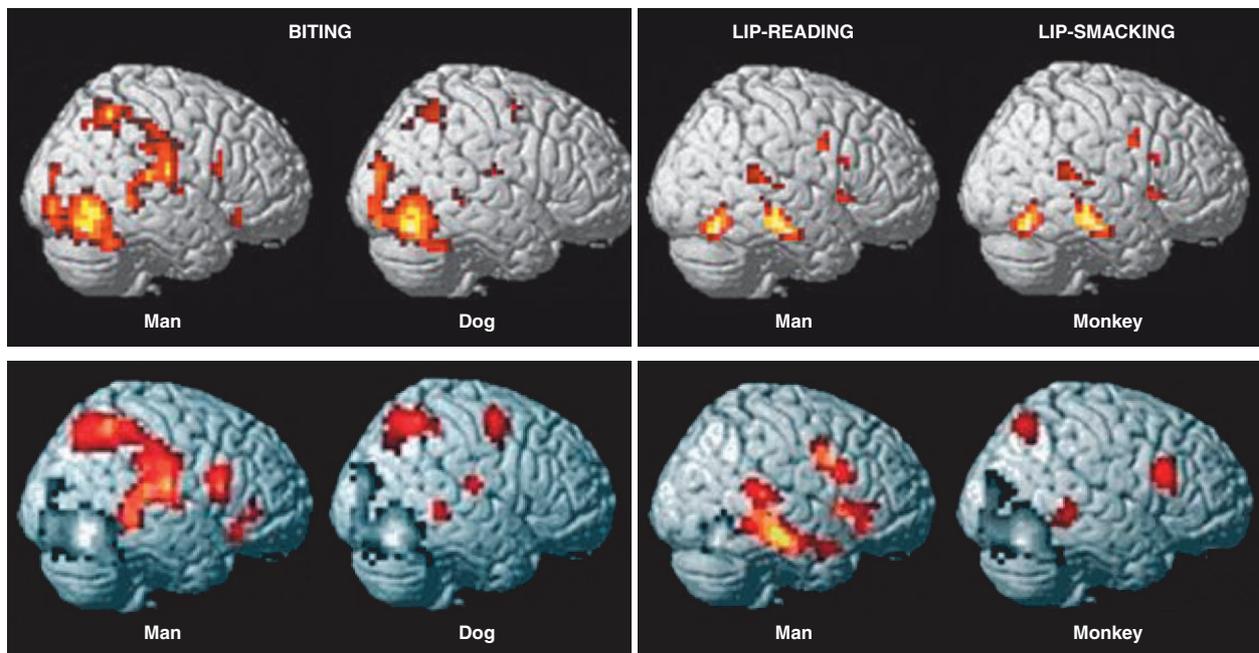


Figure 8. Buccino et al.'s (*Journal of Cognitive Neuroscience* 2004)⁽⁴⁾ original figures 1 and 3 (*upper panel*) and figure 5.9 and 5.10 (*lower panel*) of Rizzolatti and Sinigaglia, "Mirrors in the brain", *Oxford University Press* 2008⁽⁴⁷⁾. For brevity, only two representative sets are shown in this figure to highlight the differences between the two sets of "identical" images.

that the social deficits typical of these patients are down to a dysfunctional MNS, the experimental results so far produced in support of this are less than convincing when taken as a whole. Indeed, Figure 9 compares the results of an EMG experiment we carried out on non-autistic eight-year-old children with those reported by Cattaneo et al. in *Proceedings of the National Academy of Sciences of the USA* 2007⁽⁷⁾, and later reiterated in figure 5 of Rizzolatti et al., *Nature Clinical Practice Neurology* 2009⁽⁴⁴⁾. These Authors maintain that autistic children demonstrated no motor activation signalling anticipation of execution or mirroring during observation, unlike non-autistic children. When we repeated this experiment, however, on non-autistic children, the slope clearly shows that the EMG start rising after the child picked up the food (time zero) and it is far from the typically-developing child proposed in Rizzolatti et al., *Nature Clinical Practice Neurology* 2009⁽⁴⁴⁾, bearing a greater resemblance to the ASD slope.

Our experimental protocol and data processing were identical to those reported in Cattaneo's paper⁽⁷⁾, assisted and overseen by a child neuropsychiatrist, a neurosurgeon and a neurophysiopathologist, and although further in-depth examination will be required, it is already evident that simple experimental protocols

and models cannot describe such complex systems. The discrepancy between the results of the two experiments (Cattaneo et al.⁽⁷⁾, Pascolo et al.⁽³⁸⁾) clearly demonstrates the need for careful interpretation of data before jumping to erroneous conclusions⁽²⁴⁾.

□ DISCUSSION

Today most of the scientific literature takes the stance that the concept of mirror neurons is yet to be fully validated, particularly in humans. Indeed, MNS experiments carried out using fMRI possess enormous limitations associated with the purely haemodynamic method and probabilistic relevance⁽⁴¹⁾, and this review, among others, has shown that even the very first invasive experiments on monkeys that led to the formulation of the paradigm itself should not be taken as gospel. What was in fact the object of measurement? Was it the "mirror" activity of a neuron, or simply an epiphenomenon involving a network of neurons? The departure point was at the very root of the research, the experiment documented in 1992⁽¹²⁾. Do U481 U483 neurons belong to a network? This appears to be the case, as they responded to the same stimulus, although in different forms and with different

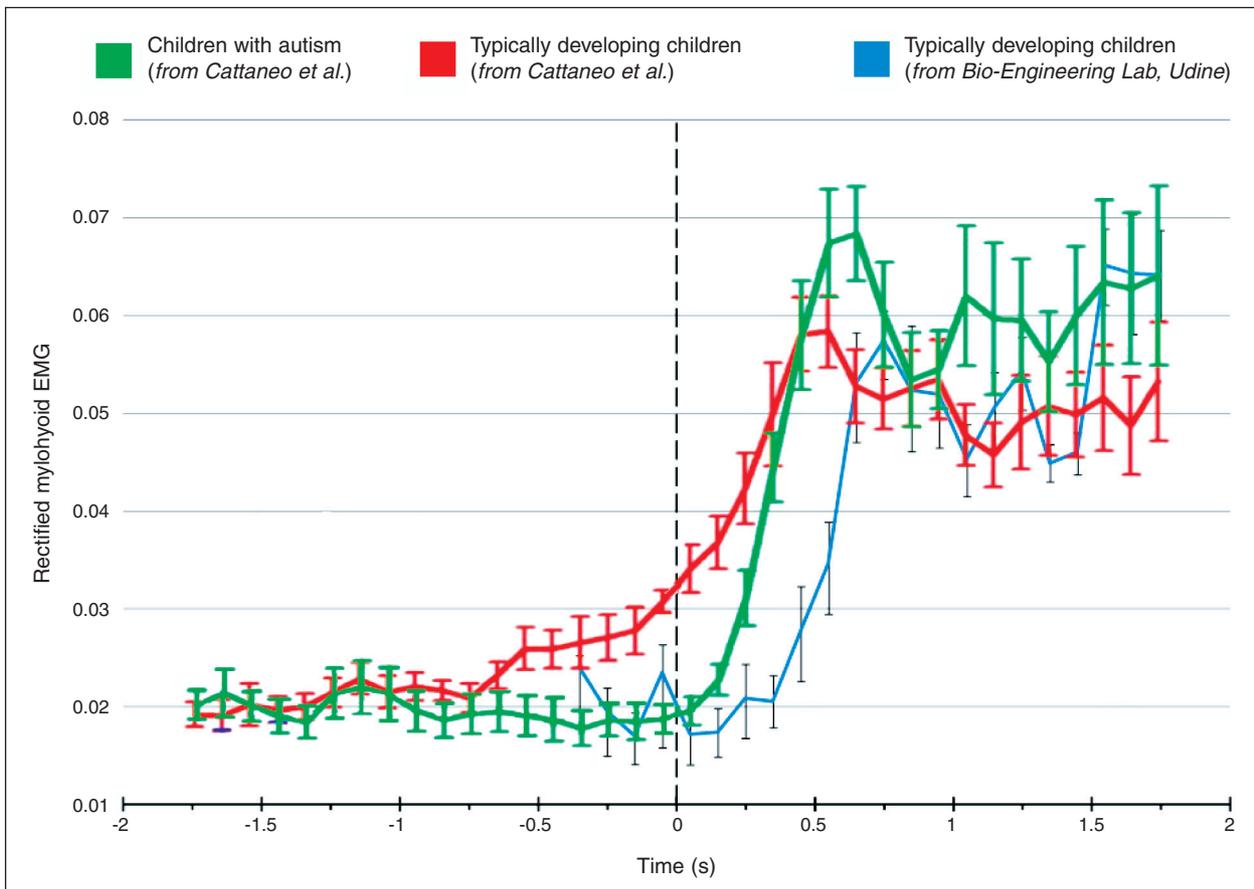


Figure 9. Comparison of the data proposed by Cattaneo et al., *Proceedings of the National Academy of Sciences of the USA 2007*⁽⁷⁾ (red and green lines) with the experiment run at the Industrial Bioengineering Lab., University of Udine (blue line).

temporal modalities. However, this network aspect has not been studied in depth, even in the following works^(20,45). In fact, studies^(12,20,45) have mainly focussed on the activities of single neurons in the cerebral premotor area F5 in response to elementary stimuli generated by a gratifying element, i.e., food. This narrow focus on single neurons, rather than the whole system, has no doubt played a part in generating the MNS paradigm.

In our opinion, however, in the seminal 1996 works^(20,45), presented again in 2001 and 2006, not only did the monkey not mirror the experimenter, simple subtraction showed that it also probably anticipated him by 0.25 s⁽¹⁴⁾. In addition, the calculation of averages and the repositioning of recordings (histograms) give indications that are incompatible with the MNS paradigm. Indeed, it is possible to provide an example that demonstrates how results similar to those proposed in Figure 5 and Figure 7 of this work can be produced without the need to invoke the MNS.

Suppose that the reader of this paper is kitted out with dozens and dozens of hypothetical microelectrodes and just as many acquisition channels. A) First the hypothetical experimenter wonders aloud “How much is 6 multiplied by 6?” and then provides an answer “36.” B) The experimenter then asks the reader “How much is 6 multiplied by 6?” and, the reader will undoubtedly say “36.” It is likely that at least one neuron will fire during the first phase of the exercise (A), because “6 multiplied by 6?” is a well-known operation that brings to mind 36, and a second firing will be recorded when the reader will says the number 36 out loud (B): The result? A new Figure 5. Now suppose the experimenter asks him or herself “How much is 13 multiplied by 7?” and then responds “91”. In this case, it is likely that weak activity during the neuron firing or no firing at all will be registered, whereas a clear signal will be detected when the reader is asked to respond to the question, thereby creating a new Figure 7. Is the MNS driving

the result or rather previous conditioning and motivation? Since there must be a strong correlation between brain activity and external (observable) activities, the logic and methods of the experiments used to demonstrate that this link is ascribable to the MNS theory leave much to be desired.

In 1988, Gentilucci et al.⁽²³⁾ state: “many F4 neurons responded passively to stimulation of the face and actively to arm movements [...] thus the organization of movement representation in F4 is different and more complex than that in F1”. Although no mention was made of area F5, this experimental evidence confirms, if any such confirmation were needed, that the “electrochemical” information passing through the various neurons is based on various criteria (among which availability) and not on purely deterministic factors. The processes linked to execution are therefore more likely to be “locally” distributed rather than committed to certain neurons that carry out specific functions or exclusive activities. The neurons are all connected in different ways and by different paths. These connections can be understood in the light of the requirement to execute similar processes from time to time, but with neurons that may be different to those used previously. In the cases in question, one also has to consider the effect of the electrodes, placed near to or inside each other. Only a locally “decentralized” structure can survive an “attack” from the outside (electrodes, illnesses, etc.), as damage to a single neuron or a set of them (only few neurons were intercepted in the experiments) should not hinder the functioning of the whole brain system. i.e., redundant connections can be used to substitute the destroyed ones, and occupied neurons can be “replaced” by unoccupied ones.

Finally, if one considers that in the experiments examined, the neuron itself fired/did not fire according to the type of action observed, and fired during the execution, it follows that the neuron should not operate in the presence of concurrent and/or anticipated or unknown acts⁽⁴⁶⁾. Hence, in functional and circuitual terms the mirror effect is highly improbable.

Even if one examines the exercises presenting the neuron’s delay with regard to the experimenters, MNS does not mimic the action observed with sufficient accuracy to make one think of a “copy” or simulation process (see numeric values reported in Figure 5 and 7). In other words, it is not simulation that allows the animal to understand what the meaning of an action is. The MNS paradigm would

therefore assume validity only at the end of the interpretation of the observed action (goal-oriented) and not at the beginning of the action itself⁽⁸⁾. The prevailing impression is that of an over-eagerness to construct a mind theory, even from the earliest experiments. Indeed, in di Pellegrino 1992⁽¹²⁾ there is already a mention of the motor theory of perception, and the Authors hypothesize “... that premotor neurons can retrieve movements [...] also on the basis of the meaning of the observed actions”.

The expression “mirror neuron”, suggesting that there is a distinct population of neurons that perform a mirroring function, does not allow for the idea that common neurons, owing to more or less complex efficiency, also perform “mirroring” activities⁽⁵¹⁾. In other words, if there is a group of neurons that activate when a “grasping” gesture is executed, prepared or observed, this is just one of the many events that needs to take place in a network, or a subset of networks, required to manage a phenomenon as complex as that which controls motor action. While this control undoubtedly involves the prefrontal cortex as the prime agent, this chain of action will also involve the primary motor areas, the sensitive areas, the supplementary motor area, basal ganglions, cerebellum and the motor neurons of the spinal cord.

Understanding an object, action or circumstance must take place very quickly, and these recognition processes only need milliseconds via the visual path⁽²⁶⁾, for example. However, the firing characteristics of mirror neurons measured in the experiments are in the order of seconds, indicating that these are more likely to be an epiphenomenon of the recognition, approval and subsequent action planning or, even more simply, could pertain to prediction or anticipation of the action yet to follow, or all of these events put together: actual or virtual.

□ CONCLUSION

In other words, the experiments analysed in this paper appear to measure the function undertaken by a group of neurons in a certain timeframe, rather than a property of a particular type of neurons that sets them apart. It is therefore expected that in the future we will recognize mirror-type activity in more or less coherent clusters of common neurons, thereby completely overturning the paradigm itself. It is this Author’s belief that the doubts raised in this essay should be put to scientific debate for a more profound

reflection, as the falsification elements (Popper) of the paradigm are consistent and well correlated^(10,25,35). This is a particularly urgent matter, as despite the fact that the original paradigm has still to be fully accepted or rejected, it has already started to influence treatment protocols, particularly in the fields of rehabilitation and autism.

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Original article**□ Reflecting on mirrors**

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SUMMARY: Since their discovery, mirror neurons have opened new avenues that may help us to discern the neural basis of many cognitive behaviours, like action understanding, imitation, language, theory of mind and “mentalism”. Many articles have been published in support of or refuting the involvement of mirror neurons in these cognitive functions, from both anatomical and physiological perspectives. For example, the concept of “action understanding”, a function ascribed to the mirror neuron system with which we are purportedly able to interpret and comprehend the actions of others, has been refuted on at least eight fundamental points, while, at the opposite end of the spectrum, other researchers are placing great faith in the mirror neuron hypothesis, convinced not only that it can explain human behaviour and abilities, but also postulating that the same cognitive processes in which mirror neurons are supposed to be involved could be affected in neurological disorders like autism and autistic spectrum disorders. They base this conviction on the fact that autism reflects the alteration of different nervous structures and activities in the brain, as well as information processing and synaptic connections. In particular, they say, the deficit in autistic subjects of affective and emotional behaviour; and their impaired ability to understand it in others could be due to an alteration of the mirror neuron system function. The potential connections between autism and the mirror neuron system functions are numerous, and could involve imitation, theory of mind, empathy and language. In this “broken mirror hypothesis”, the mirror neuron system is used as an explanation for the mechanisms underlying autism, but this is hotly disputed. This review aims to give voice to both proponents of the mirror neuron system and those who oppose it to provide the reader with an overview of the situation as is, as well as an insight into the history of the mirror neurons and what their future may hold.

KEY WORDS: Autism, Broken mirror hypothesis, Imitation, Mirror neuron system.

□ INTRODUCTION

The mirror neuron system was discovered by chance, just as Fleming happened upon penicillin in 1928, when a group of researchers led by Rizzolatti came across a particular set of neurons in the inferior frontal gyrus and the inferior parietal lobule able to activate whether the subject was performing or observing a motor action⁽⁴¹⁾. They made this discovery while they were studying the activity of specialised neurons active in the control of hand actions (object manipu-

lation) in the ventral premotor cortex of the monkey. This prompted the publication of reams of literature documenting the search for an equivalent system in humans^(6,20,40,42,44), but, since Rizzolatti’s initial paper was rejected by a famous international research journal because of its “lack of general interest”⁽⁴²⁾, the MNS has been dogged by controversy^(12,43).

Among the list of its theoretical functions, the MNS is reputed to be involved in “action understanding”, where self-generated actions possess inherent meaning, which can also be accessed by observing the same

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LIST OF ACRONYMS AND ABBREVIATIONS: **ASD** = Autistic Spectrum Disorder; **EMG** = ElectroMyoGraphy; **F5** = inferior frontal gyrus; **MNS** = Mirror Neuron System; **STS** = Superior Temporal Sulcus.

action in others⁽²⁴⁾. Mirror neurons were hypothesized to support action understanding based on findings by Gallese et al.⁽¹⁸⁾, who recorded neuronal activity from certain cells in the F5 area of the frontal cortex of macaques during action observation, but not when the objects were merely observed. To rule out any visually imperceptible movement, the neuronal activity of the hand area of the primary motor cortex and the electromyographic activity of several hand and mouth muscles were recorded during observation, which elicited no response in either case. This appeared to make it clear that something was going on in the brain when the monkey observed a “meaningful” action, i.e., someone picking up a banana, rather than just the piece of fruit itself, appearing to suggest that F5 is involved in sensorimotor associations. However, proving that this so-called action understanding actually exists is far easier said than done. In fact, as Fogassi et al.⁽¹⁵⁾ stated, although knocking out the F5 area in macaques does in fact prevent them physically grasping the banana, it may be impossible to prove whether they are still able to “understand” the action performed by others. Furthermore, mirror neurons have since been found in the primary motor cortex of macaques, undermining Fogassi et al.’s control and suggesting that rather than being concerned with meaning, these cells in fact act as facilitators of the motor response through *learned response*⁽⁴⁶⁾.

Kohler tried to come at the issue in another way, hypothesizing that action understanding would also be triggered by the sound related to the action in question, and found that this was indeed the case in a small minority of F5 neurons, which fired when exposed to the sound of cracking peanut shells⁽²⁹⁾. Umiltà also showed that while monkey mirror neurons do not respond to the act of picking up an imaginary banana, some of them do if the banana is real but hidden in some way (in this case behind a screen), provided, of course that the monkey knows it is there⁽⁴⁷⁾. Both of these tests would appear to indicate that it is not the gesture itself that is important, but the meaning of the gesture. However, whether these responses are sensitive to the meaning or, once again, the working memory of the action, as many sceptics believe⁽²⁴⁾, is far less easy to demonstrate. That being said, the entire theory cannot

be dismissed out of hand, particularly as Fogassi et al.⁽¹⁴⁾, in another study, showed that some neurons in the simian inferior parietal lobule, another mirror-neuron-rich area, responded when the banana was picked up for the purposes of eating, but not when it was picked up to be put in a box in a similar location to the monkey’s mouth. This led them to conclude that it was the purpose, or goal, of the action that was crucial, and that mirror neurons allow the monkey to understand the intention behind the action, although it may be the case that the monkey is responding to a feedback loop wherein the sensory event is merely associated with particular motor actions⁽²⁴⁾. Indeed, non-mirror neurons in the STS of macaques respond to several observed gestures, but not when the act itself is performed⁽⁴²⁾, suggesting that mirror neurons are not in fact necessary for action understanding. Nevertheless, it is interesting to note that the STS is connected to the inferior parietal cortex, where mirror neurons projecting to the motor system F5 are present...

It is clear that further investigation, rather than heated debate, will be necessary to clarify the situation. In fact, as the methods used so far have been somewhat subjective⁽³⁷⁾, we are almost back to square one, and that is even before we come to discuss the question in humans, in whom the presence of mirror neurons has not even been definitively demonstrated^(7,10,11). If it does exist, however, it is starting to become evident that the human mirror system does not function in a similar way to that of macaques. Indeed, as Catmur et al. demonstrated⁽⁵⁾ using motor-evoked potentials in the abductor muscles of the human hand, we can be trained to produce mirror effects by adaptive sensorimotor association, rather than action understanding⁽²⁴⁾. What is more, according to a meta-analysis by Molenberghs⁽³³⁾, damaging the human F5 area provokes no correlated deficit in action understanding, and imitation of a meaningful action triggers regions in the superior and inferior parietal lobules and the dorsal premotor cortex instead of the F5 area.

Plus, Gallese⁽¹⁸⁾ and Rizzolatti⁽³⁹⁾ et al.’s early hypothesis that mirroring is involved in speech perception, prompting a fervent revival of the motor theory, has also been disproved by the evidence, which suggests that although speech recognition may in some way be modulated by sensorimotor circuits, action under-

standing is not involved⁽²⁴⁾. Nonetheless, it may be, say the advocates, that the mirror system is merely more complex, more evolved in humans than in monkeys. Indeed, although quite distinct in humans, a correlation between action understanding and action production has been found by several Authors⁽²⁴⁾. This has led Casile and colleagues⁽⁴⁾ to postulate the presence of two separate mirror systems underlying action understanding and imitation in humans. In this scenario, one adaptable system, already present at birth, may be involved in the development of an infant's ability to imitate facial expressions, creating a feedback loop about their own facial movements and thereby evolving according to experience. A different system, described as a perception-action coupling, would be used in the case of, say, hand movements, in which observation of the infant's own movements would be essential for their evolution. Despite all the opposition, it is enormously enticing to associate the mirror neurons to human complex behaviour and disorders⁽³⁴⁾, explaining why many researchers have jumped on the MNS bandwagon. Indeed, the desire to provide debilitating neurological and psychological pathologies with such a simple explanation - and therefore a potential therapeutic target down the road - as MNS deficit or dysfunction is very strong, albeit furiously contested.

□ AUTISM IN THE MIRROR

One of the cognitive disorders most eagerly associated with a potential MNS disruption is autism^(25,35,49), or autistic spectrum disorder. Indeed, ASD subjects, with their characteristic withdrawal from social interaction and their wide-ranging cognitive impairments in social skills, verbal and non-verbal communication, coupled with restricted and repetitive behaviours⁽¹⁾, and, above all, their apparent lack of empathy, or understanding of others' intentions, would seem to provide fertile ground for further research into the MNS. Indeed, autistic behaviours are known to reflect the alteration of different nervous structures and activities in the brain, involving the cerebellum and cerebral cortex⁽³²⁾, as well as information processing and the synaptic connections between neurons⁽³¹⁾. The affective and emotional deficit in ASD subjects⁽²⁷⁾, and their impaired ability to understand others has been tentatively ascribed to the "broken mirror hypothesis"⁽³⁸⁾, i.e., an alteration of the MNS function. This hypothesis is backed up by results demonstrating

structural abnormalities in the MNS regions of individuals with ASD, as well as a delay in the activation of the core circuit for imitation in individuals with Asperger syndrome, and a correlation between reduced MNS activity and severity of the syndrome in children with ASD^(8,16). Moreover, additional evidence for the involvement of MNS in autism derives from the resting-state suppression of the sensorimotor cortex (mu waves) during voluntary movement execution and the observation of the same movement made by others, which is absent in ASD⁽³⁴⁾.

The connections made between MNS function and autism are many, involving imitation, theory of mind, empathy and language^(17,19,39). During imitation, for instance, defined as the ability of a person to replicate an observed motor act or to observe, acquire and repeat using the same observed movements⁽⁹⁾, the posterior part of the F5 area, which corresponds to the MNS, is more active^(2,3,23,26) and damage to these neurons can cause impairment in the imitations of some actions⁽²⁵⁾. Encouragingly, the activity of mirror neurons involved in imitation has been found to be less extensive in ASD subjects⁽⁴⁸⁾.

However, people with autism also show an alteration in brain activity in regions outside the MNS⁽²¹⁾, and the broken mirror hypothesis fails to explain the normal behaviour of autistic children when asked to perform goal-⁽²²⁾ or object-oriented imitation tasks^(8,45), not to mention their impeccable performance in imitation tasks when explicitly instructed to imitate⁽²²⁾. This seems to suggest that in autistic subjects the apparent deficit may arise from not knowing what to imitate or when, due to their ignorance of less explicit social cues conveyed, for example, through eye contact^(28,30). The same involvement of visual processing could also explain the difference in mu wave suppression observed through electroencephalographic measurements in autistic subjects and controls⁽⁴⁵⁾.

Moreover, a recent study on movement selectivity showed that individuals with autism exhibited not only normal functional magnetic resonance imaging responses in MNS areas during observation and execution of hand movements, but they also exhibited typical movement-selective adaptation (repetition suppression) when observing or executing the same movement repeatedly, another blow to the broken mirror hypothesis⁽¹³⁾.

Once again the experimental protocols thus far used in support of a link between MNS dysfunction and ASD are highly controversial⁽³⁶⁾. For example, EMG

of the mylohyoid muscle during the execution of goal-oriented tasks has been used to determine the time relationship between the opening of the mouth and the beginning of the movement, and thereby show a difference between the behavior of the typical developing children and that of ASD individuals. Pascolo et al. also claim to provide evidence of a deficit in action chain organization in ASD subjects and bolster the hypothesis of a broken MNS for these individuals. However, the Authors later found that mylohyoid activation is unable to discriminate between typical development and ADS subjects, and therefore “there is not enough evidence to support a link between ASD and a broken MNS, and experimental results must be carefully interpreted before developing therapeutic or rehabilitative protocols”⁽³⁶⁾. In the absence of more convincing evidence, we can only agree.

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Original article**□ Mirror neurons and free will**

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SUMMARY: *As among the prerequisites of free will is the intentionality of action (the action must be voluntarily directed towards a specific purpose), the object of analyses of the mirror neuron system, we intend to explore the as-yet speculative difference between free will in the “ontological” sense (“in the third person”, one could say) and free will deriving from a broader “phenomenological” perspective (“in the first person”) of the perception of intentionality in human actions. The former can be traced back to Libet’s famous research on the timing of volitional acts. The counterintuitive - revolutionary according to many - results of Libet’s experiments lie in the comparison of subjective decision timing with neural timing: the brain activity involved in the initiation of action began in the prefrontal motor cortex well ahead of the moment in which the subjects seemed to have made a decision. The “phenomenological” perspective has to do with the psychological “construct” of the intentionality of others. A robust body of literature now exists that tries to comprehend moral reasoning by exploring its potential “pre-moral” constituents, or the construct of the intentionality of others. The idea, tackled from several different perspectives, is that in order to understand moral judgment, one must first understand the mechanisms used to build the “grammar of action”, or the deciphering of observed behaviour. In this sense, the mirror neurons make it possible to understand the actions of others “from the inside”, encoding them in terms of one’s own motor possibilities. In the judicial category of the subjective element of crime, we believe we can identify phenomenological free will, or the phenomenon on the basis of which the actions of others appear to us as free and agential: this is a necessary premise so that these free actions can be considered, upon further mental evaluation, punishable.*

KEY WORDS: *Free will, Intentionality, Mirror neurons, Neurolaw, Phenomenology.*

**□ MIRROR NEURONS
AND TWO VIEWS OF FREE WILL**

“The sight of agony has no effect on me whatsoever. I kill a man as I drink a glass of wine”: this is how the *poète-assassin* Lacenaire summed up his complete lack of empathy. Cesare Lombroso, who studied Lacenaire (along with other famous criminals of the time) while writing his most important book, *L’Uomo delinquente* (Delinquent Man), moves from his case to a blanket statement: what seems to characterize

subjects such as Lacenaire is the selective loss of the ability to empathize with the suffering of others: “The first to disappear is that feeling of compassion for the misfortune of others, which, according to some psychologists, is so deeply rooted in our being”(page 127)⁽¹²⁾. In the emerging field of research known as neurolaw, empathy, and more generally the mechanisms underlying the ability to “mentalize” the behaviour of others, have become of fundamental importance.

Firstly, studies on empathy and the ability to mentalize

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are part of a broader, classical field of study encompassing forensic medicine and psychopathology and regarding the analysis of the basic psychic abilities required for fitness to stand trial; in other words, the study of mental pathologies that can qualify a person who commits a crime as legally insane. In particular, the ability to empathize has played a central role in the longstanding debate on the medical and legal status of the nosological category of “psychopathology”. In this regard, the discovery of so-called mirror neurons in the macaque ventral premotor cortex has been extremely important. The mirror neurons discharge during goal-oriented actions, but also when the macaque observes somebody else, for example, grasping an object with a precision grip. The whole mirror mechanism “appears to play a fundamental role in both action understanding and imitation”⁽¹⁴⁾. According to numerous studies, this seems to hold true in humans as well⁽¹⁶⁾.

As “the mirror-neuron system provides the essential physical other-to-self mapping that is necessary for comprehending physical actions of intentional agents”⁽²²⁾, it may be possible to attempt to draw from the phenomenological perception of intent a distinction within the general concept of free will, regarding in particular its application to jurisprudence and neuropsychology. Free will is generally characterized by two conditions: a) the possibility of doing otherwise; in other words, the agent can choose between alternative courses of action; and b) self-determination: the agent determines which course of action to take.

Among the prerequisites of free will is the intentionality of action; in other words, the action must be voluntarily directed towards a specific purpose, which is the object of the analyses of the mirror neuron system. In this paper, we intend to further explore the as-yet speculative difference between free will in the “ontological” sense (“in the third person”, one could say) and free will deriving from a broader “phenomenological” perspective (“in the first person”) of the perception of intentionality in human actions.

The link between the two different approaches to the conceptualization of human free will takes on a certain importance from the privileged point of view of forensic neuropathology. By ‘privileged point of view’, we mean that the practical needs (and socially sensitive function) of judicial activities sometimes seem to be particularly effective in heuristic terms, and bring to the fore certain theoretical questions that might otherwise remain unexplored or overlooked by academic researchers. The point of view of forensic

neuropathology, which necessarily requires pigeonholing in one judicial category or another, seems somehow bound to emphasize the distinction between matters that concern what we may define as “ontological” free will (the problem of the existence of the ability to act freely in humans, or lack thereof) and those which concern what we may define as “phenomenological free will” (the study of the characteristics on the basis of which our actions, and especially those of others, appear to us to be free).

□ “ONTOLOGICAL” FREE WILL

The concept of “ontological” free will can be traced back to Libet’s famous research^(9,10) on the timing of volitional acts. The counterintuitive - revolutionary according to many - results of Libet’s experiments lie in the comparison of subjective decision timing and neural timing: the brain activity involved in the initiation of action is begun in the prefrontal motor cortex well ahead of the moment in which the subject seems to have made a decision. Indeed, volunteers became conscious of their decision to act about 350 milliseconds *after* the onset of type II motor readiness potential (typical of unplanned, spontaneous acts) and 500 to 800 milliseconds *after* the onset of type I motor readiness potential (typical of planned, conscious acts). The volitional process thus seems to begin unconsciously, since the brain readies itself for action much earlier of the moment in which the subject becomes aware of their decision to act.

The results of Libet’s experiments, which had long been questioned but have been confirmed in essence by a series of experiments repeated under stringently controlled lab conditions, seem to indicate - indeed, according to Libet and a great many contemporary scientists, they *prove* - that our actions (or at least the types of actions subject to this research) are caused by preconscious cerebral activity, which is only subsequently registered consciously, on average only 206 milliseconds before the act is performed with regards to intention (the so-called W judgement, after will), and 86 milliseconds before with regards to the act itself (the so-called M judgement, after movement). Many have inferred from these findings that conscious intentions are not behind our volitional actions, because they arrive after cerebral motor preparation activity - which is inaccessible to our consciousness for a certain period of time - and appear only once the process that results in movement has already been

launched. In this light, according to many Authors, Libet's experiments show that intentions are not the true cause of our actions, because the true causal work is performed by neural processes that precede it in time. If this is true, then intentions are causally ineffective or, in technical terms, "epiphenomenal". Without getting into the debate that followed, or discussing the sophisticated research on the subject⁽²¹⁾, here we will merely point out here that in the legal field, Libet's research has often been associated with the construction of the model of the mind in legal subjects: in other words, they have been taken as paradigmatic examples of *new sciences*, which, if taken seriously, could (and should) call into question one of the underlying assumptions of the main Western judicial models: that of the implicit consideration of a penal subject as being free and fit to stand trial (except in the presence of pathological causes) and thus fit to be punished.

In our opinion, this perspective encompasses all the positions - defined as "radical" by others^(2,6,7,18) - of those for whom the possibility of "scientific proof" of the absence of free will necessitate revision of the retribution framework of penal systems. Without burdening our argument with excessive legal references, we will only point out that the legal counterpart of the "ontological" perspective of free will is the concept of imputability (sanctioned by art. 85 in the Italian penal code), whose formal axiom is that the subject liable for penal action must be *imputable*, and thus "in full possession of his or her faculties," i.e., endowed with free will. Imputability as a legal concept thus has to do with problems related to *ontological* free will: if the latter exists (whether proven scientifically or as a legal convention) the subject is imputable; if it is lacking (again, whether according to science or legal convention) the subject is not imputable.

□ **"PHENOMENOLOGICAL" FREE WILL:
THE PERCEPTION
OF INTENTIONALITY**

The other perspective with which *neurolaw* grapples with "freedom" of action in humans has to do with the psychological "construct" of the intentionality of others. A robust body of literature now exists that tries to comprehend moral reasoning by exploring its potential "pre-moral" constituents, or the construct of the intentionality of others.

The idea, tackled from several different perspectives, is that in order to understand moral judgment, one must first understand the mechanisms used to build the "grammar of action", or to decipher observed behaviour. In this sense, the mirror neurons make it possible to understand the actions of others "from the inside", encoding them in terms of one's own motor possibilities. Indeed, "although there are several mechanisms through which one can understand the behaviour of other individuals, the parieto-frontal mechanism is the only one that allows an individual to understand the action of others 'from the inside' and gives the observer a first-hand grasp of the motor goals and intentions of other individuals"⁽¹⁷⁾. More specifically, as stated by Sinigaglia and Rizzolatti, "it seems almost obvious to assume, at least at first glance, that the attribution of actions to the self or to the other should be based on separate neural representations. Two distinct neural networks should underlie our and others' actions. However, it is just this kind of assumption that the discovery of the mirror mechanism has radically undermined. Indeed, what the functional properties of the mirror mechanism tell us is that the self and the other are so strictly intertwined that, even at the basic level, self- and other-attribution processes are mutually related to each other, being both intimately rooted in a common motor ground^(4-5,15,19). More precisely, the mirror mechanism clearly indicates that (i) in order to be attributed either to the self or to the other, actions should be represented as actual motor possibilities for the agent and (ii) the distinction between self and other should stem from their shared motor goals and motor intentions, because it is on the basis of this common motor ground^(4-5,15,19) that we are able to differentiate ourselves from the other selves." (page 69)⁽²⁰⁾.

Based on current knowledge, what emerges is that the grammar of intention is partially grounded in immediate understanding, made possible by the mirror neuron system.

"The chain organization of the cortical motor system provides the mirror mechanism with the possibility to encode not only single motor goals *per se* (e.g., reaching, grasping, holding, etc.), but also motor goals as being intentionally related one to another, thus representing the motor intention with which they might be achieved (e.g. reaching for grasping for bringing-to-the-mouth or reaching for grasping for moving-away). The richness of our motor repertoire does not depend only on the fineness-of-grain of motor goal representation; rather, it essentially relies

on our capability to represent from the inside more and more complex goal architectures, recruiting them both when we perform a given action and when we observe someone else performing it. This capability critically contributes to shaping our experience of ourselves and of other selves, providing us with a multilayered motor representation both of our own and of others' action possibilities." (page 71)⁽²⁰⁾.

Of course, not everything is due to the mirror system, as many studies have shown. For example, "recent research suggests that the inference of others' intentions from their observed actions is supported by two neural systems that perform complementary roles. The human putative mirror neuron system is thought to support automatic motor simulations of observed actions, with increased activity for previously experienced actions, whereas the mentalizing system provides reflective, non-intuitive reasoning of others' perspectives, particularly in the absence of prior experience"⁽¹¹⁾. So, in general, observing all gestures compared to observing still images is associated with increased activity in key regions of both the mirror neurons system and mentalizing systems.

It is also interesting that: "The richer and more diversified our motor repertoire, the sharper our sensitivity to others' actions, so that our capability to make sense of others turns out to be rooted in our capability to make sense of ourselves. It follows that, if more individuals share the same motor repertoire, the richer and more diversified such a motor repertoire is, the more these individuals will be able to be mutually reflected by their own motor possibilities, thus coming to a more and more fine-grained understanding from the inside of each other. In other words, the more individuals share their own motor repertoire with each other, the more fine-grained is the experience they make of action possibilities when these action possibilities are relative both to their own selves and to other selves." (page 71)⁽²⁰⁾.

From a more general perspective, in an analysis of the various dynamics through which the attribution of causality affects the interpretation of actions and omissions, Cushman and Greene⁽¹⁾ (who in other instances adopt positions discussed in the first paragraph), conclude that "the moral distinction depends on processing features of non-moral cognitive processes such as causal attribution and intentional attribution".

Turning to research in the naturalistic-neuroscientific field, a fruitful perspective - which, as we shall see, may have a connection with simulation theory - is

that of *moral grammar*, as proposed by Hauser⁽⁸⁾ on the basis of the ideas Rawls⁽¹³⁾ set out in "A Theory of Justice". This perspective aims to address, through an innatist and biological approach, the problem of the intercultural similarity of moral intuition, and of basic judicial rules regarding murder, incest, theft, etc. In particular, Hauser - albeit with a great deal of emphasis on the evolutionary element (and thus formally far removed from phenomenological tradition; the relationship between phenomenology and naturalism is a highly complex area of philosophical thought, which we cannot tackle here) - touches upon a central issue in the scientific exploration of moral thought, namely the study of the semantic aspect of behaviour as the fundamental premise for any further analysis. The starting point of this approach is the introduction of a structural analogy between the forms of language organization and those of intentional conduct. Indeed, much like language uses discrete elements combined and re-combined to create an infinite variety of expressions carrying meaning (from syllables to words to full sentences), so do "Actions appear to live in a parallel hierarchical universe. Like phonemes, many actions lack meaning. When combined, actions are often meaningful. [...] When actions are combined, they can represent an agent's goals, his means, and the consequences of his action or the omission of an action." (page 47)⁽⁸⁾.

Human behaviour can thus be represented as a text whose structure immediately expresses a "sign-meaning" relationship: if in a text the main relationship is that between the expressive plane (sign) and the content plane (meaning), in intentional behaviour the main relationship is that between manifest behaviour (sign) and its underlying mental states (meaning). The conduct manifested thus becomes a "sign" in terms of "something that stands for something else" (this was the definition of "sign" given in Medieval schools: *aliquid stat pro aliquo*), in this case the underlying mental states. Upon this Hauser bases his argument, which is directly tied to the study of moral psychology. Recalling the idea of universal (and innate) grammar proposed by Noam Chomsky, he suggests that similar principles may also underlie moral behaviour. Much as the existence of a universal grammar relating to the automatic, innate (and universal, in light of the use of constant, inter-cultural principles) nature of language is postulated, so is the existence of a hypothetical moral grammar proposed, with the same set of basic principles. "For language, we recombine words and higher-order combinations

of these words (noun and verb phrases). For morality, we recombine actions, their causes and consequences. Like Chomsky, Rawls suggested that we may have to invent an entirely new set of concepts and operations to describe the universal moral principles.” (pages 47-48)⁽⁶⁾.

Universal moral grammar makes it possible to identify fundamental moral rules underlying the different expressions of cultural systems: the psychological mechanism of assessing a given action is generally shared, albeit with potentially different parameters. And the premise of such a moral grammar must inevitably be likened to a sort of behavioural grammar, a syntax and set of semantic rules through which we interpret the behaviour of others. It is interesting to note how this “semantic consubstantiality” of social behaviour crops up again within a modern phenomenological approach, in its proposal of a “third way” as an alternative to the traditional bi-partition of theories on social cognition⁽⁹⁾. In summary, the two main perspectives are the “theory of theory” and the “theory of simulation”. The former holds that our understanding of others rests upon the psychology of common sense: the behaviour of others, which is unknowable and, in itself, inferred, just like any other natural phenomenon, through the use of a cognitive theory, and, more specifically, this theory sees others as agents endowed with thoughts and intentions. In contrast, simulation theory holds that the understanding of the behaviour of others is mediated by an act of simulation, through which observers put themselves in the shoes of the person being observed: by projecting one’s own mental state, the mental states of others can be understood. An explicit theory is therefore not necessary, since understanding derives directly from the act of identifying with the other.

On the basis of this interpretation of social cognition, the crucial mechanism is neither the use of “theories” of the mind, nor the implementation of “simulation processes”, but rather the immediate carrying out of an intentional behaviour associated with a meaning (that is, endowed with a semantic nature).

“Mirror activation, on this interpretation, is not the initiation of simulation, it’s a part of a direct intersubjective perception of what the other is doing. At the phenomenological level, when I see the other’s action or gesture, I see (*I directly perceive*) the meaning in the action or gesture.” (page 179)⁽⁶⁾. And furthermore: “Expression is more than simply a bridge that closes the gap between inner mental states and external bodily behaviour. While seeing the actions

and expressive movements of the others persons, one already sees their meaning. No inference to a hidden set of mental states is necessary. Expressive behaviour is saturated with the meaning of the mind; it reveals the mind to us.” (page 185)⁽³⁾.

On the basis of this hypothesis, then, the close parallels between the mechanisms of language and those of social cognition lie in the fact that in both cases, the phenomenon encountered by the subject is a *semantic phenomenon*, in which the strictly perspective plane (the ink markings in a written text, the body movements of the other) is augmented by a sign plane, which is associated with something else (the meaning of the written words, the intention of the other). For our purpose, the point that needs to be stressed is that the issue of moral and legal responsibility (and that of free will) finds fertile ground in the microscopic examination of the psychological mechanisms through which we “construct social phenomena”: the way in which our brain leads us to perceive the action of another as determined/non-agential (an involuntary jostle that causes us to trip on a bus), and at another time leads us to perceive it instead as voluntary-agential (a punch thrown by an over-excited fan during a game). The deciphering of this behavioural text precedes any moral judgment (involuntary push = excusable action: “Don’t worry, the driver hit the brakes too suddenly”; vs. a voluntary punch = reproachable action: “I’m going to call the police”).

A clear example of how neuroscience can help elucidate psychological mechanisms can be found in the case of mirror neurons. As argued by Gallagher and Zahavi, they seem to put into action a psychological mechanism that one can readily find (with a minimum of self-examination) in one’s own immediate experiences: we think we are able to understand others by mirroring ourselves in them, or putting ourselves in their shoes. It is only after this very quick “reflex” that we are able to judge - in the broadest sense - the behaviour of others.

In this sense, neurolaw helps us distinguish the various perspectives of the conceptualization of free will. Indeed, if we wanted to limit the above discussion to the legal realm, we realize that the concepts that can be summed up by the idea of phenomenological free will belong to different legal categories from the concepts related to ontological free will. In other words, the ways in which the law deals with the “perception of intentionality” in a crime suspect are those that fall in the category that can be summarized as “culpability”, or a subjective element of the crime.

The law requires that objectively illicit behaviour (*i.e.*, *contra ius*) be accompanied by a morally reproachable mental attitude: in the Italian Penal Code, art. 43 summarizes the three forms of “reproachability”: *malice, guilt and premeditation*. In the Anglo-Saxon legal system, the corresponding legal category for the psychological element involved in crime can be found in the concept of *mens rea*, which is considered an essential element of illicit behaviour, together with the “material” component of *actus reus*. What is of most interest to us in our neurolegal analysis is the fact that this legal category (different from the category of liability discussed with regards to “free will in the third person”) deals with the ways in which law has regulated the evaluation of attribution (and thus also the “construction of intentionality”) with regards to illicit acts. In other words, the law, in an entirely implicit way, independently from any *theory* on moral judgment, has established that the premise for attributing responsibility lies in the fact that the imputable act has been “perceived” by the judiciary body as *intentional* (that is, with a purpose) and that this *intentionality* is reproachable on the basis of the psychological attribution attached to it (*malicious or culpable*).

Thus, in the judicial category of the subjective element of crime, we believe we can identify *phenomenological free will*, or the *phenomenon* on the basis of which the actions of others appear to us as *free and agential*: as we have said, this is a necessary premise so that these free *actions* can be considered, upon further mental evaluation, punishable (that is, deserving of reproach).

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Original article**□ Mirror neurons and the predictive mind**

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SUMMARY: *Our brain is not only a reactive organ, capable of reacting quickly to the stimuli that arrive from the external environment, but also, and above all, it is a pro-active organ that allows us to make hypotheses, anticipate the consequences of actions, and formulate expectations, thereby enabling us to wrong-foot an adversary. Without this ability, humans would not be able to interact with each other, nor create forms of social coexistence. Certainly evolution has spurred the higher cognitive functions to develop mechanisms of reorganizing action according to unforeseen events as quickly as possible, integrating them into a perception-action cycle that may only take fractions of a second. Recent neuroscientific advances have shown the fallacy of imagining an anatomical and functional dichotomy between perception and action. The discovery of mirror neurons has shown that there is, instead, a very close link between perception and movement, confirming the existence of a relationship between what we perceive and how we act that hinges on the activation of the same neural substrate in both cases. In light of this evidence, perception becomes the ability to interpret an object in terms of the potential movements and actions that the perceiver could activate in relation to it. Motor acts are formulated and anticipated through the joint activity of perception and action and a mechanism of embodied simulation, which automatically perceives "the other" as an agent like oneself whose actions can be predicted on the basis both of their similarity to one's own motor repertoire and the physical characteristics of the situation in question.*

KEY WORDS: *Anticipation, Embodied action, Mirror neurons, Perception.*

□ INTRODUCTION

The idea that perception involves not just the interpretation of sensorial messages but, first and foremost, an anticipation of the relevant action is hardly new. In 1852 Lotze⁽⁷⁾ pointed out the close relationship between perception and action when he argued that the organization of sensorial data is the outcome of its integration with information gleaned from the muscles. Similarly, van Helmholtz (1962)⁽¹⁷⁾ attributed motor control with the ability to match sensations with forecasts based on the motor command itself. In France, Janet (1935)⁽⁶⁾ highlighted the

predictive nature of perception - an action (possibly restrained) that adapts not merely to the stimulus that provoked it but also to all the other potential stimuli generated by the action itself. "This adaptation to a set of purely possible future stimuli characterises perceptive modes of behaviour" (Janet, 1935, page 31)⁽⁶⁾. To clarify this concept, Janet used the example of an armchair. When we simply look at an armchair, we do not think we are performing an action, but actually this is an illusion: "we have the characteristic action of an armchair already inside us, what we have called a perceptive schema, which in this case is the act of sitting down in a certain fashion in this arm-

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LIST OF ACRONYMS AND ABBREVIATIONS: GMP = Generalized Motor Programme.

chair” (Janet, 1935, page 43)⁽⁶⁾. Just like a biological simulator, our brain draws on memory and formulates hypotheses for movement, predisposing the action best suited to the situation, prior to making any movement. Bernstein (1967)⁽¹¹⁾, one of the fathers of modern physiology, claimed that planning a motor act, in whatever way it is codified by the nervous system, necessarily implies recognition of situations which are bound to happen but do not yet exist⁽¹⁸⁾.

The lengthy evolutionary process of the human species has generated a variety of adaptive biological mechanisms: the architecture of the skeleton, the subtle properties of sensorial receptors, and the formidable complexity of the central nervous system. These mechanisms have solicited our brain to formulate interior models of the body and the world around us that reflect the over-arching laws of nature and permit the survival of each and every animal^(8,9). Bernstein was one of the first investigators who tried to go beyond the traditional description of motor regulation and coordination as a linear succession of four phases: prediction, preparation, execution and verification. He proposed a model based on the action- perception cycle in which the fundamental element is a discriminator that establishes the so-called “required value”. This value has three important functions:

- 1) it identifies the gap between a movement as predicted and as executed, providing a correlation between the two;
- 2) it enables the recognition of a completed act, making it possible to go on to the next act in a motor sequence;
- 3) it performs an adaptive function: confronted with something unforeseen, corrective impulses are triggered to re-establish the initial plan of action.

The higher cognitive functions have certainly evolved to develop this ability to reorganize action according to unforeseen events in the fastest possible way in order to give the organism in question a competitive advantage and therefore a better chance of survival. In this way, new events are integrated into the perception-action cycle in only fractions of a second. Hence there must be existing formulae and traces of the movements and actions that have been acquired over time in the central nervous system. Indeed, the existence of such schemata is demonstrated by the fact that we can rely on habitual actions and automatic movements⁽¹⁾.

□ MIRROR NEURONS AND ANTICIPATED ACTION

The traditional idea that perception and action are two distinct processes from a neurophysiological point of view, in which perception is the product of ‘associative’, primarily temporo-parietal, areas while the control of movement relies on motor and pre-motor areas localised in the rear part of the frontal lobe, has been called into question by some recent findings. In particular the discovery of mirror neurons^(4,13) has made it necessary to redefine this relationship, highlighting the dimension involved in human cognition. A number of experiments carried out on both monkeys and humans have shown that the mirror neurons - located in the pre-motor and rear parietal cortex - are activated both when we perform an action and when we see that action performed by others⁽⁵⁾. In other words, the observation of another’s action appears to generate a sort of internal simulation of that action through a mechanism that is sub-conscious, automatic and pre-linguistic. In fact, the activity of the mirror neurons indicates that the motor response is already present in the perception phase: we are no longer dealing with a sequential process, as was traditionally thought, but with a sensorimotor cycle in which the action is not the final outcome of the perceptive process but already an integral part of it. Thus, the ability to predict our own actions or those of others depends on the existence of a system of motor mediation for perception itself⁽¹²⁾ that can be considered a form of perceptive simulation of movement. In this sense, predicting the meaning of others’ actions does not necessarily involve recourse to forms of inference or reasoning. Rather, it is based on an immediate combination of perception and action. This also disposes of the presumed difference between action as something “active” and perception as something “passive”: the latter would in fact contain a sort of embodied intentionality capable of guiding the action towards specific goals. In practice, without the information provided by perception, motor acts would lead nowhere.

According to Berthoz⁽²⁾, the presence of mirror neurons confirms the existence of a repertoire of pre-perceptions through which the brain is able to simulate actions, foresee their consequences and choose the most appropriate course. In the light of this,

perception cannot be viewed as the mere interpretation of sensorial messages; rather, it involves an internal simulation and anticipation of the consequences of an action. Think, for example, of champion skiers. They do not stop at monitoring, and, if need be, correcting the trajectory of their descent on the basis of the information supplied by their sensory organs. They go over the route mentally, anticipating the various stages and imagining possible responses even before an error occurs. Only occasionally does the brain compare the incoming data from the sensorial receptors with the predictions made previously. A discrepancy between the two will cause the skier to make corrections and modify the angle of the knees, speed, etc.⁽²⁾. The same goes for other sports. Without this ability to anticipate, tennis players would systematically miss the ball, since hundreds of milliseconds are bound to elapse between synchronizing the muscles needed to take up a correct posture for reception and the moment at which the racquet attains the right inclination, during which the ball will have travelled several metres. This, in fact, is exactly how beginners tend to behave, showing why it is necessary to establish the direction of the ball and its trajectory in advance. In other words, during an action the brain appears to activate two parallel processes: one conservative and the other projective⁽²⁾. In the first, which is the more primitive, the brain behaves as a controller, trying to maintain certain variables within the limits defined by the intended action. It deploys gestures, mostly primitive ones, whose characteristics are already codified in specialised neuron groups present in the brain (basal ganglia, motor and pre-motor cortex, cerebellum, etc.). The potential errors involve mechanical quantities such as speed, force etc. The second, projective process has evolved more recently, and uses internal “maps” to simulate a movement without performing it. Through simulation, this process makes it possible to predict the consequences of potential actions and “choose” the best one for the situation⁽³⁾.

□ MEMORIES, AIMS AND PLANS AS EMBODIED ACTION

In order to act successfully, one has to be able to remember. Memory is a set of sensorial and motor schemata and habits serving as a system able to recall corporeal perceptions; in a nutshell, it can be called

embodied action. Procedural memory conserves, albeit at the level of potential, the possibility of actions that have not yet been implemented. Thanks to the perceptive traces of events already experienced and deposited in the memory, we are able to anticipate the future, preparing the appropriate actions to achieve a certain goal.

All the evidence suggests the importance of a proactive physiology that engages in a more lively and direct manner with the surrounding environment than that foreseen by the traditional reactive view of physiology. There is now widespread consensus that perception is generated by different reference systems suited to the actions in progress. In fact, while the receptors measure ‘derivatives’, the brain mobilises a repertoire of prototypes of shapes, faces, objects and even synergies of movements. The evolution of the brain has produced laws that tend to simplify the geometric, kinetic and dynamic properties of natural movements. But perception is also predictive, thanks above all to memory, which anticipates the consequences of the future action by matching them against those of a past action.

One of the theories most often used to explain the relationship between perception, action and memory - and, in particular, to relate prediction to the consequences of past action and the record of its consequences - is Schmidt’s schema theory (1975)⁽¹⁴⁾. This is based on two fundamental concepts: the GMP and motor schema. The GMP is a motor pattern deposited in the memory and representative of a class of actions that possess the same general structural characteristics (invariants). Among these we can identify:

- a) the sequence of muscular contractions involved in a gesture;
- b) the temporal structure, meaning the proportion of time used to carry out each single segment of a movement, which remains constant even if the total time of the movement changes;
- c) the relative force, meaning the constant proportion between the forces expressed by the various muscles that participate in the action, independent of the degree of overall force.

During the action, the generalized motor programme can undergo variation and be adjusted to adapt to the various situational requirements. This is made possible by the alteration of certain parameters such as the selection of specific muscles or the force and duration of the movement. In fact, one particular movement repeated over and over again will never be identical, particularly in the world of sport, even if its funda-

mental structure remains unchanged, thereby confirming the existence of a generalized motor programme. Such variations are possible thanks to the motor schemata that represent a generalization of concepts and relationships between concepts deriving from experience. This makes it possible to identify the specific requirements for putting into effect a particular version of a motor programme⁽¹¹⁾. In other words, if on the one hand the generalized motor programme provides the invariants in the desired gesture, the motor schema selects the specific parameters of the motor response to adapt them to the situational requisites. This schema becomes all the more precise the greater the variations in the parameters applied to the same motor programme. Let us imagine, for example, that as he steps up to take a penalty kick a footballer processes the environmental information and selects the motor programme he considers most appropriate. He will know how to adapt the generalized motor programme to the specific situation, modifying such parameters as timing and extent of movement, foot position, and so on, to meet the specific requisites of the situation⁽¹⁶⁾. The schema becomes increasingly precise as the variability in any one motor programme increases. In fact, with each variation of class, and the increase in accuracy of the feedback, the schema is updated and established as a generally valid rule. At the same time, specific information is eliminated, which solves the problem of having to store an excessive amount of data.

Schmidt⁽¹⁵⁾ distinguishes between two states of memory based on the relationships between the four sources of information, clarifying two aspects of his concept. The schema of *recall* enables a new response, providing the generalized motor programme with the necessary parameters for carrying out the movement and adapting it to the requisites of the task in hand. While the schema of *recognition* enables evaluation of the level of appropriateness of the movement undertaken, comparing the incoming sensory feedback with what was foreseen and making any necessary corrections. This makes it possible to anticipate the sensory consequences of the response and compare them, both during and after the movement, with the incoming feedback. In this way information about the result is obtained, and any deviation between the expected and actual sensorial consequences is recognised as an error.

A very similar concept was formulated by Neisser⁽¹⁰⁾, who considers perception as a 'cycle' in which the fundamental structures are anticipatory schemata,

meaning programmes of action that prepare the subject to acquire certain information that will, in turn, modify the original schema. In light of these considerations, it no longer seems plausible to subordinate the motor functions to the "higher" mental activities, as if the body were inferior to the mind. Indeed, even though they form part of different systems, perception and action are two closely integrated functions. In terms of evolution, both have contributed to selecting motor schemata and predictive capacities that we still use today, millions of years on, to adapt to the environment around us.

□ CONCLUSIONS

The experimental data that has been acquired over recent decades has shown that the classic dichotomy between 'the brain that knows' and 'the brain that acts', i.e., between perceptive processes and motor functions, is now hard to endorse or apply, except for purely analytical purposes. The phylogenetic development of the higher-order areas can no longer be viewed as a mere reinforcement of the processing systems that intervene between sensory input, on the one hand, and motor output, on the other. One of the fundamental prerequisites for the development of the cognitive capabilities in the brains of primates was precisely the combined action of cognitive processes and motor functions. In view of these factors it seems plausible that the central nervous system has undergone not only a quantitative evolution, but also a qualitative one. If this hypothesis proves to be grounded in fact, then the anatomical connections and functional characteristics of the cortical regions that are typically considered associative, perceptive or motoric could, instead, account for the emergence of cognitive, perceptive and motor skills from the functional integration of information that can only be traced back to the individual domains in theoretical terms.

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Original article **Mirroring and simulated intentionality**

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SUMMARY: *Twenty years after their discovery, in spite of empirical evidence that points strongly towards the existence of mirror neurons in humans, not to mention the far-reaching implications of mirroring mechanisms in various branches of learning, the role of mirror systems in human cognition remains hotly disputed, particularly in Italy. Internationally, the discovery of mirror neurons appears to represent one of the greatest achievements in neuroscience, as it would overturn not only current knowledge on the structuring of cognitive working, but also epistemology itself in different branches of learning. Why is it so difficult for neuroscientists and psychologists to recognize the role of mirror mechanisms at a gnosiological level? Why are their implications so "difficult to digest" for some, and utterly convincing for others? Why is it so difficult to accept the existence of this basic mechanism, which is both elegantly simple and highly sophisticated? Is it because this would completely revolutionize our comprehension of the behaviour and intentions of other people without involving high-level actions of a symbolic-computational nature? In the attempt to provide answers to these questions, I will now present what neuroscientists have to say on the matter, and raise some merely speculative hypotheses in order to add grist to the mill. At the same time, I will try to develop the idea according to which "conceptual intentions" (theories) assigned to the others - i.e., neuroscientist proponents of mirrors - are to be assigned to "the intentions of those who watch" rather than the intentions of those who are watched. The results of research on the mirror neuron system tell us that it is through this particular class of neurons that we (as observers) grasp the intentions of others. While this seems to be a fact that contradicts the idea proposed, in this paper I will argue that this contradiction is only apparent, because the conceptual intentions attributed to others are formed on the basis of perceptual-motor patterns internalized by an observer (Buccino, Binkofski et al., 2004; Calvo-Merino et al., 2005; Rizzolatti and Sinigaglia, 2006) and therefore represent an interesting example of mirroring.*

KEY WORDS: *Mirror neuron, Neuro-conceptual configurations, Simulated intentionality.*

 WHY IS IT SO DIFFICULT TO ACCEPT THE EXISTENCE OF A SENSORIMOTOR MECHANISM AT THE BASIS OF UNDERSTANDING?

Over the last fifteen years, the debate about the issue of a body-mind relationship has been raging anew. Though some last bastions of the Cartesian separation between mind and brain still survive, it is now widely

accepted, not only by the scientific community, that thought has a biophysical rather than a 'mystical' basis. Although it is not yet entirely clear how thought can be generated through chemical-electrical processes, some of these mechanisms are now being unravelled, thanks to modern research techniques. Today, these techniques are allowing us glimpses into a world that was once unimaginable but is now not quite so mysterious.

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A major advance in this direction was made when the action of mirror neurons were recorded by a team of neurophysiologists in Parma led by G. Rizzolatti. The publication of their article set off an avalanche of related research and publications on an international scale. Despite this interest, in Italy a substantial number of researchers considered it “worthless nonsense”. According to Haldane (1991)⁽²⁵⁾, this opinion is only to be expected, as it represents the first phase in the eventual acceptance of a revolutionary theory. This outright rejection is generally followed by the second and third stages of acceptance, from “It is an interesting but erroneous point of view,” to “It is true but totally irrelevant,” and, finally, the fourth stage of complete agreement: “I have said that all along!”

More and more frequently the prefix “neuro” appears in the titles of scientific (and other) publications, to convey their association with different branches of learning, e.g., neuroaesthetics, neuroethics, neuroeconomics, neurophenomenology, neuropedagogy, neuroteaching, etc. The fact that these fields are strongly connected with the implications of mirror working is clear, but as yet there is no consensus: some researchers stress the specificity and effects generated by mirrors, while others entirely reject their existence in man.

One of the most fascinating things to arise from this debate is that it is easier for many to accept the presence of this system in nonhuman primates than it is in human beings. Justifications for this standpoint include doubts regarding the instrumentation used and the difficulty in interpreting the results. As far as the instruments are concerned, the dispute centres around the kind of knowledge obtained through brain imaging techniques, and in particular functional magnetic resonance imaging, as this only allows indirect elucidation of what happens in a specific cerebral area⁽²⁸⁾. As regards the interpretation of results, it is difficult to discern the involvement of the same class of neurons or groups of different and overlapping cells in response to motor and perceptive stimulations. In any case, accepting the presence of a motor mechanism at the basis of comprehension in nonhuman primates, but not in humans, means ascribing to the view that evolution, despite providing such an easy and efficient mechanism of understanding the surrounding environment in our ancestors, saw fit to interrupt this mechanism in humans, presumably to make way for something far more complex. From an evolutionary perspective, this theory does not seem very probable^(11,37), and it is far more likely that we, as a species, still retain this mechanism.

So, accepting for a moment that mirror neurons do exist in humans, and in many more cerebral areas than previously thought⁽³¹⁾, the more cautious may nevertheless question the ease and speed that some conclusions regarding the role of the mirror system in human cognition have been drawn in both the cognitive neurosciences and human sciences. The epistemological and anthropological study and theory of the implications of mirror mechanisms have, however, taken a long time to publish, suggesting that they are the fruit of careful consideration rather than excessive zeal. Indeed, mirror neurons were discovered at the beginning of 1990s, and it was not until 1998 that the first publications with the word “mirror” in the title started to appear⁽¹⁶⁾. Those by Rizzolatti were not published until 2004⁽³³⁾, and the first comprehensive review of experiments on the new role ascribed to the sensorimotor system is dated 2006⁽³⁴⁾.

So, why is there so much resistance to mirroring in humans? Is it because this particular class of neurons provides a simple explanation of some aspects of our mind that have been previously been considered too complex to explain in physical terms? Does the fact that neurophysiologists and neurobiologists are now encroaching on the territory once considered the preserve of psychologists (like Mind Reading, ego, memory, language, etc.) or philosophers (conscience, free will, etc.) create a barrier? Is it the idea that the mind, being capable of extraordinary creations, cannot share anything with something so humble as the sensorimotor system? Perhaps we are so used to making things difficult that we find it hard to believe that there is a neural mechanism so powerful to start, but not complete, the conditions granting us the skills to think, understand, learn, remember and relate to others. But the brain has taken thousands of years to ‘learn’ to work the way it does today! Evolution does not use theories to select the most effective mechanisms to produce adaptive answers, but instead tries and tests actions and tools to determine the most useful and economical means of survival.

According to proponents of mirroring, it is likely that evolution led to the development of a mechanism to allow primates (among other creatures) to perform the vital function of instrument/action relationship mapping. Indeed, mirror neurons are said to map the relationship that links an object or a tool with what we can do with it, its purpose⁽¹⁸⁾. In fact, research shows us that this special class of neurons does not activate itself in relation to the kind of object or its physical characteristics (an apple or a cup), but in relation to the

purpose of the action: eating an apple or putting it back in a box activates different mirror neurons because the purposes of the actions are different⁽¹⁰⁾. This mechanism enables the observer to immediately understand, at the neural level, the aim or intention of an action performed by somebody else as it is observed, because the mirror activated has in itself the object-purpose relationship that is being observed. Thanks to this anticipation, induced by the behaviour we have observed and the context of the action, things have an immediate, pre-reflexive and pre-linguistic meaning⁽²⁷⁾.

One of the most challenging aspects of this research is that comprehension of the action, i.e., understanding the intention of the action to which it is connected, is indissolubly linked with the contents of our sensorimotor system⁽³⁴⁾. Indeed, research has demonstrated that the sight of acts performed by others will elicit different cerebral activity in the observer, depending on their prior motor knowledge⁽⁶⁾. For a subject who is learning, this could mean that the possibility of understanding a new concept will depend on the degree of sharing between the motor repertoire of the observer and that of the doer, or teacher.

Perhaps the reasons for the difficulty in understand a concept, a behaviour, or a theory when involving as yet unavailable neural pathways are starting to become clear. The absence of a suitable schematic for the comprehension of a stimulation-situation could be related to:

- a) the lack of experience suited to the situation;
- b) a different mapping of the experience in question;
- c) the difficulty in finding a “structure” able to represent metaphorically the stimulation-situation to make it understandable.

Is one or more of these basic conditions at the heart of the difficulty in accept a theory that requires “neuro-conceptual configurations” too different from pre-existing configurations as valid or meaningful? I will discuss this in further detail later on (paragraph “Who does perceived intentionality belong to?”), but meanwhile, let us examine the main barriers to the full acceptance of the neuroscientific perspective in general, and the theory on the working of mirrors in particular.

□ CRITIQUES OF THE NEUROSCIENTIFIC PERSPECTIVE

Neuroscientific explanations of mental processes are often thought of as:

- a) “reductive”, because they tend to reduce what is mental into physical terms;
- b) “over-ambitious”, because they claim to have discovered the unifying theory of social cognition;
- c) “faddy” and “modish”, thanks to the seductive power of the words, techniques, and images used to describe them; and, last but not least,
- d) “self-referential”, that is to say, they tend to ignore the body of knowledge acquired by human sciences over the last years.

Let us look at these criticisms one by one.

□ THE REDUCTIONISM CRITIQUE

Those who say cognitive neuroscientists are reductive believe they have the intention or conviction of explaining even mysterious and unexplainable phenomena like conscience, capacity of choice, motivation, and memory in corporeal terms. However, neuroscientists claim that believing that what is mental is the result of processes that happen in a physical system is not the same thing as believing that mental activity is solely the activity of the nervous system⁽³⁸⁾. As Gallese⁽¹¹⁾ explains, claiming that mirror neurons enable basic aspects of intersubjectivity to be understood from both phylogenetic and ontogenetic perspectives does not mean that mirror neurons are thought to explain everything about social cognition since: “to make us what we are is not only the possession of a shared nervous mechanism, but also an historic path made of subjective experience which is unique and particular” (page 321). Boncinelli⁽²⁾ also emphasizes that in humans genetic heritage, the absolute lord of life and behaviour in lower animals, has to all intents and purposes abdicated, leaving plenty of space for the action of the environment, learning and education. Considering the positive consequences of brain-based epistemology, as Edelman⁽⁸⁾ states, is not the same thing as desiring a scientific explanation to reduce our “second nature”, or its ethics and aesthetics. Iacoboni⁽²⁵⁾ also warns that it is too early to extend the discovery of mirrors to fields such as neuroethics and neuropolitics; in particular, it will be necessary to avoid the enthusiasm of neuroscientists ending up in neurobiological simplification, that is to say a new version of sociobiology. These are just a few of the many answers given by cognitive neuroscientists to the issue of the mind/body relationship, and since they are the first to distance them-

selves from this risk, it is not clear why they are still considered reductive.

Reductive could, however, be used to describe those who do not take into account new discoveries made in neurosciences, “reducing” its complexity to that which is already known. To whom can the reductive attitude, or any other attribution, be assigned? What is the “sharing space” between those who attribute something to somebody and the recipient of what has been attributed? Who has the reductive attitude or any other attribution? What direction does the action of attributing something to somebody take? From the outside in, or from the inside out? Or, could there be a “shared space”, termed the share manifold by Gallese⁽¹⁴⁾, referring to the state in which mutual intelligibility can occur?

□ THE UNIVERSAL THEORY CRITIQUE

Theories based on empirical evidence produced by cognitive neurosciences have often been associated with the ambitious aim of providing a unifying explanation of human cognition. However, is it really the aim of cognitive neuroscientists to look for an explanation of the explanation, the principle of mechanisms capable of erasing the interpretations provided by all the branches of learning up to now? Does such interpretation mirror a human desire (not only that of cognitive neuroscientists) to look for the final solution to all mysteries, by identifying it according to a situation and phenomenon suited to this purpose? Although mirror neurons do seem to lend themselves to global explanations, neurophysiologists are the first to distance themselves from this temptation.

While it is true that Rizzolatti and Voza⁽³⁵⁾ talk about a “unifying vision of the bases of social knowledge” and that Gallese, interviewed by Mozzoni for BrainFactor⁽³⁰⁾, refers to the presence in the human brain of a mechanism that represents a “unifying explanation that is more economical than a series of different behavioural and clinical data”, it is also true that these Authors repeatedly stress the fact that their research is still in its infancy. They state that the huge overhaul that has been brewing since the discovery of mirror systems must be able to integrate with the disciplines that have thus far dealt with processes involved these systems, that is to say cognitive, emotional, social, creative and ethical processes.

To quote Gallese⁽¹⁵⁾: “Nowadays neurosciences are

debated very much. They are often represented in a wrong way, that is as the instruments that will give us the final answers to unsolved matters that have been debated in philosophical terms for millenniums. This kind of attitude is not shared by the majority of my colleagues, but in our country it is the result of a sensationalistic and banal way of representing the results of scientific researches” (page 48). In “Descartes’ error”, Damasio also stresses that all matters concerning the mind-brain relation can be dealt with on several levels, from molecules to micro- and macro-circuits, to social and cultural spheres, without which an acceptable explanation of mental phenomena such as consciousness, opinions, decision and memory would not be possible⁽⁶⁾. Hence, although neuroscientists seek to distance themselves from all-embracing explanations, it is certain that the mirror mechanism, just for raising so much interest, must possess some unifying features! Indeed, a system that encompasses the memory of our perceptions, actions, cognition, and emotions, and one that gives rise to an extraordinary variety of human behaviours, at this point can be considered a good candidate for providing a common basis for such different phenomena as theatrical performance, perceptive classification, aesthetic judgment, learning, economy, etc.

But, why do we reject or shy away from such a basic mechanism potentially underpinning such a wide variety of different phenomena? What leads us to believe that a potential unifying mechanism is useless or even dangerous? Is it perhaps the desire to protect the borders of our respective disciplines, believing that this is the only way to survive in the competitive world of science? What if specificity and scientific acknowledgement were in fact connected to the contribution given, from a particular point of view, by the common growth of knowledge and research of the structure that links cognitive and biological processes?⁽¹⁾.

□ THE FADDINESS CRITIQUE

Even though the popularity of applying the prefix “neuro” to every branch of learning (neuroeconomy, neuroaesthetics, neuroethics, neuropedagogy, neurodidactics, neuropolitics, neurophenomenology, etc.) is evident, it is equally clear that neuroscientists themselves are not to blame for this trend, rather those who exploit the results of the research and erroneously interpret them to suit their particular field.

The problem may lie in the translation process. It is very easy to be struck by sensational statements or original concepts, and to want to use them to further our own ends. Such appealing buzzwords as “mirror neurons” quickly become part of our vocabulary and the focus for a radical rethink, even though they are as yet far from fully understood. As Gallese states (when interviewed by Mozzoni in *BrainFactor*, 2009)⁽³⁰⁾ mirror neurons attract the attention of non-specialists because they deal with something we feel close to, even though we do not normally pay attention to it, and they are certainly far easier to understand than logic inferences or complicated symbolic processes. Who knows? Perhaps one day we will discover that mirror mechanisms - similar to those which enable imitation and active not only during socialization and learning - are behind even this, very human, attitude.

□ THE SELF-REFERENTIALITY CRITIQUE

Ascribing to cognitive neuroscientists a self-referential behaviour could represent another way through which mirror mechanisms are displayed at a phenomenological level. In other words, introducing my idea of “simulated intentionality”, the perception of someone else’s characteristics may mirror the use of a neuroconceptual configuration available to us, allowing us to use this as “pattern” to define the particular state we feel when observing or listening to someone’s performance⁽²⁹⁾. On the basis of the books we read for our research, I have never found anything resembling the scientific solipsism that is ascribed to some neuroscientists - quite the reverse! The attitude of most cognitive neuroscientists is easily recognisable in the following opinions.

For one, Damasio⁽⁶⁾ claims that knowledge acquired at different levels cannot be excluded from the survey because no-one on his own can detect everything that goes into producing the mental phenomena we know today that can be studied thanks to brain imaging techniques. Dehaene⁽⁷⁾ states the importance, in psychology and pedagogy, of knowing what neuro-images reveal about neural circuits that process graphemes and phonemes to understanding the complex process of reading. Iacoboni⁽²⁶⁾ shows that those who work in the neurosciences complement neural data with psychological data with no opposition. Gallese⁽¹³⁾ advocates the need for a constant communication between cognitive neurosciences and

human sciences to further knowledge of the workings of the mind. Practicing what he preaches, Gallese has worked with the most influential personalities from several diverse branches of learning, namely the linguist Lakoff⁽¹⁷⁾, the science philosopher Sinigaglia^(19,20,21,23) and psychologist Morelli⁽¹⁹⁾. Furthermore, among his interests are the relationships between neural correlates and various artistic forms (theatre, painting, cinema), psychoanalysis, psychopathology and narration. The fact that the first book to be published on mirror neurons was co-written by Rizzolatti and the philosopher Sinigaglia testifies to the need of cognitive neuroscientists to make use of the knowledge acquired by the human sciences over the years. In summary, it seems that the external perception of self-reference is due more to things we have read than the positions taken by a particular class of scholars. Not being able to read everything in the copious scientific literature, it is clear that we select the Authors and publications of interest to us. Thus, our choice of reading matter, and hence our perspective, is not random, but it is strongly influenced by our epistemological affinities... or is it our motor repertoires?

□ WHO DOES PERCEIVED INTENTIONALITY BELONG TO?

In relation to the behaviours assigned to neuroscientists, and extrapolating from the examples shown, it looks as if when we assign a behaviour, intention or aim to others, these are not always felt as their own by the target subjects. How can this widespread and commonplace event, considered the function of reflecting mirrors, be explained? Interestingly, it may be used by those who argue for mirror function. Let us take embodied simulation, a theory through which Gallese⁽¹¹⁾ claims that assigning intentions to others comes about through the functional mechanism (embodied simulation) that makes comprehension of the action possible. Of course, Gallese is talking about simple intentions connected with the use of an object or the observation of a motor behaviour. However, through the results of experiments on sentence comprehension, we know that simulated mechanisms behind the comprehension of the actions observed are also responsible for the comprehension of statements referring to the actions in question, regardless of whether these statements are read, heard or simply thought^(32,36).

Through research we also know that the degree of

comprehension of other people's behaviours depends on the motor repertoire of the observer, that is to say on chains of logically connected mirror neurons that work during observation, listening, reading, or also "just thinking" or imagining the behaviour in question^(4,5). By generalizing the implications of these results and extrapolating them to more complex intentions, following the principle of "family similarities"⁽³⁹⁾, one could speculate that assigning intentions to others is the result of the simulated processes themselves, which would activate to perform the behaviour in question, in this case, the neuroscientific theories. If in order to be understood, these theories required the presence of a specific motor-conceptual repertoire not yet available to those "who simulate"⁽²⁴⁾, the comprehension of the results and the theory itself would be hampered or even blocked. Indeed, sharing a particular motor-conceptual repertoire is necessary to understand other people's intentions and to imitate their actions correctly. If this condition is not fulfilled, according to this hypothesis, the brain/mind uses subsidiary circuits to arrive at comprehension.

It can be postulated that the selection of the kind of subsidiary circuit helping us in absence of appropriate conditions influences the shape of concept-target comprehension and its net of connections with other concepts. So, it is possible to assume that the comprehension of a theory, just as any other action that is removed from our schematics (which we now know have a motor basis) is the result of simulated accessory processes that produce the form of a reality which exists in the mind that perceives it. It must be clarified that according to this perspective, reality is formed in the mind of the observer, who draws on simulative mechanisms even when the conceptual repertoire of the simulator shares many neural maps with the target-repertoire. The difference between the condition in which a suitable sharing space is generated and that in which, in the absence of sharing, subsidiary repertoires come into play is that in the first case, in the presence of a base like that termed by Gallese⁽¹²⁾ as "intentional consonance" (that is the comprehension of some nervous mechanisms that lead actions, emotions and sensations) it is more probable that the construction built acquires characteristics which are more suited to attribution of intentionality to the others. In contrast, when pre-existing knowledge is weak, it is possible that the shape produced, since it stands outside the neural sharing space, could hamper mutual intelligibility,

losing subsidiary circuits that would assign our mental states (or motor schematics, depending on the level of description) to others.

□ CONCLUSION

The idea that assigning particular inclinations or intentions to somebody else (in this case to the theorists of the cognitive neurosciences) is seemingly the result of the activation of our conceptual repertoires, starting from logically connected neural chains, which act while we listen to or read the conceptual-linguistic repertoire of someone else. In other words, although it may in some ways seem counterintuitive, the intentionality assigned to the others, since it springs from simulative processes, would not necessarily belong to these others, rather it would take the shape of "simulated intentionality", that is mirrored by the observer, according to the meaning that the simulations have for them.

If a large part of the activated repertoire is shared by both the observer and the observed (in this case the researchers who make use of the results of neurosciences and the neuroscientists themselves) mirroring could produce a state of "intentional consonance" that may enable the comprehension of mutual motor representations. However, if certain theorists who assign intentions to other theorists have a very different structure from the latter, the two theories, or their respective perceptual-motor modelling, would not be easily compared if not "incommensurable", or not possessing a common "ground description"⁽⁹⁾.

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Original article**□ Mirror neurons and the 8 parallel consciousnesses**

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SUMMARY: *To understand the mechanisms that shape consciousness and the evolutionary advantages it confers, identification of the neural correlates of consciousness (NCC) is considered to be of fundamental importance. Hence, by reviewing neglect pathology, I set out to identify the brain areas whose damage causes the loss of consciousness without preventing unconscious perception. Once these areas had been identified, by analysis of the resulting neglect I sought to define a distinction between areas responsible for access to consciousness and those responsible for consciousness itself. This approach led to the identification of the anterior cingulate and the precuneus-posterior cingulate as components of access to consciousness, while the medial-superior temporal lobe, the superior parietal lobe, the anterior insula, the posterior insula, the lateral motor cortices BA 8 and BA 6, the inferior frontal lobe and the inferior parietal lobe appeared to correspond to 8 distinct and autonomous parallel real consciousnesses. Acting simultaneously, these areas give us 8 contemporaneous conscious sensations, respectively, namely 1) image perception, 2) spatial image positioning, 3) emotions related to these images, 4) presence on the scene, 5) possibility to move oneself in the scene, 6) possibility to move single objects, 7) possibility to move more than one object, and 8) feeling of being subject spectator in the theatre of consciousness. The evolutionary advantages provided by the conscious process are the ability to learn rapidly (without long training/trial and error) and a problem-solving approach mediated by mental images. All the 8 consciousnesses detailed above are thought only to be present in humans, developing as we climbed the evolutionary ladder, bringing new memory and reasoning skills, from the primitive consciousnesses that first appeared in reptiles. The neural correlates of these consciousnesses bear a striking anatomical and physiological resemblance to mirror neurons. Like the mirror neurons, the NCCs are active when we perceive both external and mental images. The seductive hypothesis that mirror neurons are in fact the NCCs is therefore also discussed.*

KEY WORDS: *Attention, Brain evolution, Function of consciousness, Mirror neurons, Perception.*

□ INTRODUCTION

Consciousness is the continuous sequence, during our waking hours, of external and internal images, of abstractions, actions, emotions, perceptions of our body and, in general, of anything that make us feel watchful. It also involves the subjective feeling of being present on the scene where events are occurring, and of being responsible for them in some way.

Authors such as Damasio^(14,15) and Edelman⁽²¹⁾ have argued, albeit in slightly different ways, that there are different levels of consciousness. However, according to these Authors, these levels of consciousness would be overlapping, interdependent and non-parallel. According to them there would be a primitive level (the only one that can stand alone), along with a further two advanced levels, which are present only in humans. An injury on the first level would prevent the existence of the two successive levels, and, simi-

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LIST OF ACRONYMS AND ABBREVIATIONS: **BA** = Brodman Area; **fMRI** = functional Magnetic Resonance Imaging; **NC** = Neural Correlate; **NCC** = Neural Correlates of Consciousness.

larly, injury to the second would block the third level of consciousness. The theoretical research I have conducted suggests that, instead, there are 8 separate types of consciousness, which, although interlinked, are capable of acting independently.

Nevertheless, another of Damasio's theories⁽¹⁴⁾, namely that levels of consciousness are linked to particular brain areas, which act as points of convergence, simultaneously holding the image of the object and the emotions (or memory of the emotions) generated by the object, does bear striking parallels with conclusions drawn from my research, and, in fact, mirror neuron theory. These issues will be discussed in depth below, but the "hard problem" concerning consciousness is the following: how is the brain able to generate the subjective experience of the self admiring a nice landscape, listening to music, wondering or simply living their everyday life? How can the brain, built of matter, give rise to these immaterial experiences? Consider the first epic chess match in which the machine, the IBM Supercomputer Deep Blue, defeated man, the world champion Gary Kasparov. Although both players were made of matter, there were clear qualitative differences between them, the so-called qualia, which form the peculiarities of consciousness. Nobody thinks that this computer "sees" or "lives" the chessboard as the man does when playing. Instead, the superior performance of supercomputers such as these are due to their tremendous memory and calculation speed, which are used by fundamentally static programs defined by software programmers.

Trying to explain how brain activity can participate in the self, some Authors, like Descartes⁽¹⁴⁾ and Eccles⁽⁴⁸⁾, hypothesized the existence of an anatomical part of the brain that linked it to the immaterial soul, an explanation that is clearly unlikely to satisfy those of a scientific bent. Other Authors⁽¹⁸⁾ assert that it is premature to try to solve the hard problem, and we would be better to focus on the location of the neural correlates of the access to consciousness. However, in this article I will have a speculative stab at both, by postulating the location of the neural correlates of the access to consciousness and consciousness itself, and providing a tentative explanation of the conscious process.

By the neural correlates of the access to consciousness,

we mean the brain areas responsible for the attention-access and memory-access specific to consciousness, without which the appearance of consciousness would not be possible. These concepts are very different from the unconscious attention and memory implicated in the perception of animals that are not conscious, i.e., fish, in whom unconscious attention is needed to focus on some goal (e.g., food) selected by their emotions. In such beings, unconscious memory is needed to store images relating to previous experiences so that they can be recognized, and duly acted upon, at a later date. As we will see, unconscious emotion, attention and memory are also used in conscious animals to identify (unconsciously) the object of perception that the attention access and memory access will make conscious. This attention access is thought to serve to activate evolutionary new brain areas, present only in conscious animals, namely the neural correlates of consciousness. In theory, these connect and simultaneously activate the cortical areas dedicated to external perception and the corresponding brain areas responsible for memory access of similar or equivalent perceptions. In this way, the NCCs are thought to give rise to conscious perception.

In order to shed light on these issues (NC of access to consciousness and NCC) we reviewed a large body of work on neglect pathology. Theoretically speaking, identifying the effect of neglect in certain areas should enable the development of further hypotheses on the functioning of consciousness and the evolutionary advantage it provides, thereby providing a tentative solution to the hard problem of consciousness.

□ METHOD

The working method adopted here used the two following criteria to identify the brain correlates of access to consciousness and consciousness. The first was aimed at identifying the parts of the brain that are solely responsible for consciousness. Indeed, there are areas whose injury causes damage to consciousness but whose function is not dedicated exclusively to this task⁽⁶¹⁾. For example, a severe injury to the brainstem, located at the base of the brain, can cause coma. In this situation, evidently, conscious perceptions

are absent, but so are unconscious perceptions, therefore the brainstem does not fit our profile. Instead, we need to look for brain areas whose injuries prevent the existence of consciousness, but do not compromise unconscious perception. After identifying such areas, the next step is to distinguish between those areas that control access to consciousness and those that can be considered NCCs.

In order to achieve the primary endpoint (identifying brain areas whose sole function is consciousness), a large body of work concerning neglect pathologies was reviewed. Neglect is a disorder characterized by loss of consciousness of sensorial information on the left. It is usually caused by unilateral lesion in the right part of the brain, in even just one of the different areas with specular counterparts in the left hemisphere. Only the lesion on the right is capable of causing the disease, because it seems that the right brain is able to perceive both sides of external space, while the left hemisphere seems to perceive just that on the right. Hence, if the left side is injured, there would not be strong evidence of loss of consciousness, as the right brain can perceive all space. Instead, a lesion in the right brain does not allow perception on the left because the intact left brain is only able to perceive the information present on the right⁽³⁰⁾. Thus the patient with neglect is not able to report which images are present on the left side of their environment, and shaves only on the right, etc.⁽¹⁶⁾ However, it has been shown that such a person is able to unconsciously perceive the images placed on the left⁽⁴³⁾. This makes neglect an ideal situation for identifying the correlates of cerebral consciousness. Indeed, the first of the above 2 criteria is fulfilled, i.e., a lack of consciousness in the presence of unconscious perception.

Due to these factors, neglect has long been a focus in the study of consciousness, especially concerning the role of attention (access) in conscious perception. However there is a dispute regarding the cause of the neglect: for some it is due to an attention deficit, for others, to a lesion of the conscious representation^(62,63). To satisfy both parties, neglect is now being described not as a unitary disorder, but as a complex set of attention and consciousness deficits^(2,62,63). So the areas that are subject to neglect should correspond to the sum of the areas responsible for access to consciousness (attention areas, and in my opinion, even memory) and those responsible for consciousness itself.

To fulfil the second criterion, that is to distinguish the correlates from the Access to the NCC, once all brain areas whose damage causes neglect have been

identified, we need to identify which areas can be linked to access to consciousness, and to propose that the remaining areas correspond to the NCCs. With this objective in mind, in addition we set out to examine the consequences of bilateral lesions resulting in the neglect. Thus it became apparent that there are 2 distinct areas where bilateral lesion results in total loss of consciousness, making them seem ideal candidates for the access-to-consciousness function. Furthermore, bilateral lesion of each of 8 other separate areas causes only loss of the corresponding type of consciousness, preserving the functionality of the other 7, indicating them as the NCs of 8 different and parallel consciousnesses.

□ THE NEURAL CORRELATES OF ACCESS AND CONSCIOUSNESSES

Examination of the literature reveals a total of 10 areas whose damage apparently causes right-sided spatial neglect^(10,28,42,62,63,65), namely the anterior cingulate (Brodmann area BA 24-32), the precuneus-posterior cingulate (BA 23, 7, 31), the posterior insula, the anterior insula, the medial-superior temporal lobe (BA 22, 37), the superior parietal lobe (BA 7), the lateral motor cortex BA 8, the lateral motor cortex BA 6, the inferior frontal lobe (BA 44-45-46) and the inferior parietal lobe (BA 39,40). Due to the key role of the anterior cingulate in conscious attention⁽⁴⁹⁾, it can be allocated to the access-to-consciousness group without further ado. Similarly, the precuneus-posterior cingulate cortex, as the seat of higher-order memory and a source of mental images, should belong to the same group. Indeed, there exists a considerable body of literature^(5,8,9,67) in support of the fundamental role of this large parietal area in the different types of memory (semantic, episodic and autobiographical) and in the production of mental images.

If the anterior cingulate and precuneus are the access to consciousness, let us suppose that the remaining 8 areas correspond to the NCC. By careful examination of neglect, it is possible to obtain confirmation of this preliminary supposition, and to understand how these 8 NCCs control 8 different and wholly independent consciousnesses. First, damage in the right hemisphere to even a single one of each the 10 areas we are examining is sufficient to cause the complete loss of left-side spatial awareness. This would suggest that consciousness is formed of 10 closely related and interdependent parts. If this were true, we would

expect that a bilateral lesion (that is both right and left) to one of these cortical areas would be sufficient to cause the loss of both left and right spatial awareness, i.e., a total loss. In actual fact, this effect is only produced in 2 of the 10 areas, namely the anterior cingulate and the precuneus, i.e., our NCs of access to consciousness. Indeed, in monkeys bilateral anterior cingulate cortex lesions cause an inability to perform abstract reasoning: the animal can learn only with the stimulus-reward-response routine^(55,59), as do fish and amphibians, which are presumably not conscious. Likewise, Damasio⁽¹⁵⁾ describes 2 patients with “zombie-like” behaviour, one of whom had a lesion of the anterior cingulate and the other a lesion of the posterior cingulate-precuneus. These subjects could only perform automatic actions without being aware of it.

Bilateral lesion of each of the other 8 areas may cause some deficits, but not enough to prevent consciousness as a whole. For example, bilateral lesion of the medial-superior temporal cortex causes semantic agnosia⁽⁵⁴⁾, that is the inability to recognize objects, and therefore a loss of conscious perceptual ability, while the other functions of consciousness remain intact, i.e., the patient is still conscious of their movements, body, emotions and so on⁽²⁷⁾. In a similar way, bilateral lesion of the superior parietal lobe only causes simultagnosia, the inability to perceive more than one object at a time. The patient cannot see the environment as a whole and can only examine it at a particular point in time⁽⁶²⁾, but the remaining functions of consciousness continue to be present. Bilateral damage to the frontal premotor areas also fails to produce severe deficits, but it does cause various types of apraxia. These disorders of voluntary movement become evident only when the patient tries to carry out motor tasks that cannot be performed automatically, like those which involve complex motor sequences, producing symbolic gestures or mentally representing a particular movement.

Although these data appear to confirm the role of the anterior cingulate and of the precuneus as the constituents of the access to consciousness, as bilateral lesion in one or in the other prevents the emergence of consciousness itself, the other data only leads us to assume that there are 8 different parallel consciousnesses, interacting with each other but independent, and therefore capable of autonomous existence, as bilateral lesion damage to each one of them does not affect consciousness as a whole to any great extent. To explain how, in neglect pathology,

damage to a single of the 8 potential NCC areas in the right hemisphere is sufficient to cause the complete loss of consciousness on the left, we must bear in mind that, although not interdependent, these areas do interact. Hence, the lesion of just a single NCC in the right brain disconnects it from the other 7 and effectively weakens the entire right side in favour of the left. When the lesion is bilateral, the deficiency affects right and left sides of the brain to the same extent. This establishes a balanced weakening of only the consciousness driven by the two damaged symmetrical areas, without affecting the other consciousnesses.

To obtain a total loss of consciousness, therefore, it would be necessary to cause bilateral damage to the neural correlates of attention or memory or, alternatively, the neural correlates of all 8 consciousnesses. This presumably occurs in dementia, particularly in Alzheimer’s disease (which, in my opinion, produces the most fitting clinical example of “zombies”), as the damaged brain areas^(23,32) in this disease correspond almost perfectly with the above-described NCCs. The first symptom of this disease is memory impairment due to lesions of the hippocampus, which is thought to play a role in storing environmental images and accessing them during later recall. In subsequent phases of Alzheimer’s, the brain progressively deteriorates, generating gradual amnesia for semantics, motor apraxia, temporo-spatial disorientation, personality changes, severe speech impairment and loss of the patient’s awareness of their deficits, until all autonomy is lost. All of these symptoms are caused by lesions in areas coinciding with the NCCs, and, naturally, if the lesions involve the immediate anterior cingulate or precuneus, i.e., the access to consciousness, consciousness deteriorates more rapidly.

By studying the different ways in which neglect can appear, through functional magnetic resonance imaging of the injured areas, we can obtain further confirmation that the 8 NCCs may control 8 different types of consciousnesses. Indeed, several studies into neglect^(28,65) have shown intriguing findings to this effect when these areas are damaged. For example, lesions in the posterior right insula cause hemisomatagnosia⁽³⁷⁾, a loss of corporeal consciousness in half of the body. In severe cases, patients may come to believe that their right leg belongs to a stranger, and attempt to throw it out of bed (somatoparaphrenia)⁽⁶⁴⁾. A lesion to the anterior right insula, on the other hand, causes anosognosia^(37,66), a lack of

awareness of disability, in this case left leg paralysis, thought to be due to an emotional deficit. This deficit is so strong that the patient may claim to be able to undertake various sporting achievements⁽¹⁴⁾. The functions of these 2 brain regions are confirmed by fMRI studies showing activation of the posterior insula during body awareness⁽⁶⁰⁾, and the anterior insula during emotion⁽⁵⁶⁾. Likewise, damage to the right superior temporal and/or medial temporal lobe causes a particular type of neglect, known as allocentric neglect⁽¹¹⁾, which is mainly focused on the perception of objects, i.e., “what” the patient sees. It is characterized by the fact that the patient can explore space to their right and left, but does not have the perceptual or semantic awareness of the left half of objects, irrespective of their spatial position⁽³¹⁾. As previously mentioned, bilateral lesion causes semantic agnosia. The fMRI data showing that these areas are active in both perception and in imagining objects⁽⁴⁴⁾ will be discussed below.

Lesions of the right superior parietal lobe cause spatial neglect, depriving the patient of positional awareness, making them lose the “where” of objects in the left side of space. Furthermore, damage to the right BA 8 causes motor extrapersonal neglect, while lesions in the right BA 6 in the dorsolateral frontal lobe causes motor peripersonal neglect⁽¹²⁾. These patients are not aware of their movements in left-side space, either near or over their own body. In contrast, a BA 44-45-46 lesion in the right inferior frontal lobe causes a self-centered motor neglect, characterized by the inability to perform a particular action sequence. fMRI confirms the involvement of these 3 motor areas in the 3 respective movements^(28,65).

Damage to the right inferior parietal lobe causes egocentric spatial neglect with a loss of awareness of the position of the body in left-hand space. fMRI has highlighted the role of this area in situations where there is a first-person perspective, such as the identification of the patient’s position in space, the imagination of an act or the representation of their own body⁽⁴¹⁾. Stimulation of this area causes the patient the sensation that they are levitating and looking down on their own body from above⁽⁴⁾.

Thus, the posterior insula is apparently responsible for body consciousness (including hunger, thirst, etc.), the anterior insula for emotional consciousness (pleasure, pain, fear, etc.), the superior temporal lobe for perceptual or semantic consciousness (the “what”), the superior parietal lobe for consciousness of the spatial position of objects (the “where”), the

motor cortex BA 8 for personal motor consciousness (movement in space), the motor cortex BA 6 for peripersonal motor consciousness (movement of the hands of the monkey, near or on its own body), the inferior frontal lobe for subjective motor consciousness of being the doer (consciousness of a sequence of actions, i.e., self-recognition in a mirror, and the ability of chimps to stack boxes to retrieve a banana), and the inferior parietal lobe for subjective spatial consciousness of being the spectator, that is the feeling of being present in the Theatre of Consciousness.

□ HYPOTHESIS ABOUT THE VARIOUS STAGES OF CONSCIOUS PERCEPTION

We now examine the different steps that may occur during conscious perception. For simplicity’s sake we will refer only to conscious visual perception because this has been the most studied to date. Hypothetically speaking, the entire sequence would unfold as follows:

- Step 1.* Emotion guides selection of the most important image from those unconsciously reaching the occipital lobe from the outside world.
- Step 2.* The thalamus focuses unconscious attention on that particular image.
- Step 3.* The image “moves” from the occipital lobe to the inferior temporal lobe.
- Step 4.* From the inferior temporal lobe it then “moves” to the superior temporal lobe.
- Step 5.* The anterior cingulate cortex, seat of attention access, keeps the image active in the medial-superior temporal lobe (NCC) for 300 ms, long enough for it to become consciously perceived.
- Step 6.* During this time interval, the visual NCC keeps the brain areas in control of the external image interconnected with those in control of the specular image of Memory-Access. The simultaneous activation of these two brain areas gives the feeling of conscious perception.

Looking at *Step 1* more in depth, many Authors, including Panksepp⁽⁴⁷⁾, LeDoux⁽³⁸⁾, Damasio^(14,15), Edelman⁽²¹⁾, and, more recently, Denton⁽²⁰⁾, have shown, albeit with different emphasis, that there is a close bond between the emotional values system, innate and acquired, and consciousness. Following this line of reasoning, among all the images perceived

unconsciously at any given moment, emotion selects that most important to the viewer. For example when you enter a room, you get an immediate unconscious overview of the objects in the room. If you are hungry, it is likely that your emotion centres will select a sandwich to bring to the fore, whereas if you are thirsty, a glass of water, or if you are looking for something, the object you are searching for, etc. According to this theory, even the solutions to mathematical-abstract reasoning problems are likely to be selected through the emotion that signals their correctness. In terms of visual perceptual consciousness, it is known that environmental images do in fact arrive at the occipital lobe: first to the primary cortex V1 and then to secondary V2-V3. Given the connections between V2-V3 and emotional centres^(34,58), it can be hypothesized that perceptual information is sent from these visual areas to emotional centres like the amygdala, septum, and n. accumbens. Here it would be subject to a selective evaluation on the basis of innate needs (hunger, thirst, seizure of territory, etc.) or needs acquired over time.

The product of this selection would then arrive at the thalamus (*Step 2*), responsible for selecting the image. Indeed, many Authors (e.g., Crick⁽¹³⁾) ascribe the thalamus' great importance as the seat of attention. As this attention is also present in fish and other supposedly unconscious animals, it cannot be considered as directly related to consciousness, so herein we will refer to it as "unconscious" attention.

In *Step 3*, the thalamus would act in such a way that perception of the selected stimulus is transferred from the occipital lobe to the inferior temporal lobe neurons that are able to unconsciously recognize the identity of the selected object (e.g., a sandwich, a glass of water, lost keys, etc.). This is confirmed by the work of Logothetis⁽⁴⁰⁾ on vision, which demonstrates that only the image that will later become conscious reaches the inferior temporal lobe, while the images that remain unconscious do not go beyond the occipital lobe. Evolutionarily speaking, all of these mental operations that lead to selection and unconscious perception are also present in fish and amphibians, which are considered here to lack consciousness. In higher species, evolution produced new brain structures, which are precisely the neural correlates of access to consciousnesses and consciousness itself. It is hypothesized that in the brain of conscious animals, the unconscious part, similar to that possessed by fish, serves to select the perception that will become conscious.

In conscious animals the image would pass from the inferior temporal lobe responsible for unconscious visual perception to neurons in the medial-superior temporal lobe (*Step 4*), which may postulated as the NCCs responsible for perceptual or semantic consciousness. In theory, these neurons are responsible not only for visual consciousness, but also for the consciousness of all the perceptions arriving from a particular object through all five senses, which enable the identification of the semantic object itself. In fact, inferior temporal lesions cause visual agnosia, i.e., the patient is unable to recognize certain objects visually, but they can identify them by touch or smell, for example.

Similarly, lesions of tactile sensory areas can cause tactile agnosia without impairing the ability of recognition through other, undamaged, pathways. The difference between visual perception and, for example, tactile perception⁽⁶⁸⁾ of the same object will depend on the difference between the two respective sensory cortices. Medial-superior temporal damage, on the other hand, causes semantic amnesia, completely blocking object recognition by any of the 5 senses⁽⁵⁴⁾.

Regarding *Step 5*, according to Libet⁽³⁹⁾, the interval between unconscious perception and awareness is 300 ms. The anterior cingulate (attention access directly linked to consciousness) would have precisely the function of activating the medial-superior temporal lobe and the NCC responsible for the other consciousnesses. In this way they exert their action and the percept becomes conscious.

As mentioned in the introduction, some Authors have stated that for now we should limit ourselves to just studying access to consciousness, as neither identifying the NCCs nor solving the "hard problem" seem to be feasible at the present time. These Authors have used magnetic resonance imaging to identify the neural correlates of access to consciousness^(17,19,24), and, looking at their results, from the standpoint we take in this article, you can actually see that the areas that these Authors consider as neural correlates of Access include many of our NCCs. In fact, from these works we can extrapolate that 150 ms after the onset of a visual stimulus on the screen occipital lobe activation occurs (visual impulses), in 200 ms that of the inferior temporal lobe (unconscious visual memory), in 300 ms the anterior cingulate (attention), and in 350-400 ms the superior temporal lobe (NCC of perceptual consciousness). Simultaneously the precuneus (memory) and other areas such as the inferior parietal lobe

and inferior frontal lobe are activated, which we hypothetically label as NCCs.

During *Step 6*, the NCCs would function as a point of convergence. In the specific case of visual consciousness, the medial-superior temporal lobe would keep simultaneously active both the occipital and inferior temporal cortices responsible for visual perception and the precuneus-posterior cingulate seat of conscious memory. So, to obtain conscious external perception, in addition to the image arriving from the environment, the corresponding specular memory for that picture would need to be simultaneously activated and superimposed. Conversely when the consciousness is arrived at through visual mental images from the memory, as the precuneus-posterior cingulate, the superior-medial temporal lobe would also need to keep simultaneously active the neurons in the sensorial cortices (occipital and inferior temporal), which have been the source of the external visual perception in the corresponding previous experiences. There would therefore be continuous feedback and alternation between activation of the neurons responsible for perception and those responsible for memory. With mental images there would obviously be a predominance of precuneus memory, while during external perception the prevailing activities would be in the sensory cortices. In confirmation of this hypothesis, fMRI studies^(25,44) have shown that the neurons of the inferior, medial-superior temporal lobes and the precuneus are active both when an image of an external object is visualized and during mental imagery of the same object from memory. There is also a gradient of increased activity in the inferior temporal lobe for the external image and vice versa in the precuneus during mental imagery. This situation is mirrored when one makes a mental image of a movement⁽²⁹⁾, which always stems from the precuneus. This also provokes activation of the BA 6 of the frontal lobe (NCC of the peripersonal motor consciousness) and the primary motor area, both of which are also active when one actually makes the movement.

Extrapolating from these findings, prolonged attention from the anterior cingulate would enable not only the NCC of perceptual consciousness to function, but also the NCCs that control the other consciousnesses to process their tasks. For example, the superior parietal lobe would act as a point of convergence between the neurons that sense the spatial position of the object and recollection of the same or similar positions in stored memories. Similarly, the NCCs of the different

consciousnesses, in addition to feelings stimulated by the external image, would activate the memories related to some need (body consciousness), emotion (emotional consciousness), potential movement (motor consciousness), potential sequence of actions (Author consciousness) and the physical presence (spectator consciousness) that this particular image has aroused in the past. In this way, the 8 different consciousnesses would take shape in a simultaneous and parallel manner. All these consciousnesses would be related to that particular object or event perceived in its surroundings. The experience of this conscious perception would then form a new memory that could later give rise to a new mental image. Therefore, consciousness of an object or a landscape is continually being updated as new memories are formed.

This conjecture seems to be supported by the work of A. Just^(33,45), who has shown that when we think of an apple, for example, this gives rise to simultaneous activation of brain areas dealing with the memory of the form, colour, flavour, taste and touch of an apple, and those related to our previous experiences of apples, whether these memories be motor (e.g., handling or biting into an apple), episodic (e.g., Adam and Eve) or autobiographical (related experiences). When this occurs, the main areas activated⁽³³⁾ are in fact the superior temporal, inferior parietal, superior parietal, lateral frontal motor, and inferior frontal cortices, and the insula - practically all of the NCCs postulated in this article as driving the 8 consciousnesses. What is more, other active areas are the precuneus (memory) and the primary cortices like the occipital lobe, responsible for primary visual perception, and the inferior temporal lobe, which stores the unconscious memory of the object. The anterior cingulate was not mentioned in Just's experiment, but this may be due to the experimental conditions used.

□ THE HARD PROBLEM

Interestingly, the simultaneous and coordinated activation of 8 different consciousnesses with their specific percepts and their associated memories could also provide us with a partial explanation of the "hard problem" of consciousness.

Actually the human brain thinks in 3 or 4 dimensions most of the time. With this larger number of dimensions, the subjective feeling of the self seems immaterial, which is why the solution to this problem,

falling outside our capabilities, seems so “hard” to find.

A fundamental role in this model is played by the precuneus, which seems to be the single source of memories for all the different consciousnesses. The feeling of a unique consciousness is thus given by the contemporaneity of all the different conscious perceptions linked together by the precuneus.

□ HYPOTHETICAL ROLE OF THE 8 CONSCIOUSNESSES

So, let us examine the function of these consciousnesses and the evolutionary advantage they confer. The NCCs of the various consciousnesses are the areas that are activated during learning and memory^(8,9), areas whose injury prevents the formation of mental images^(26,57). We can therefore speculate that the functions of the consciousnesses are to enable rapid storage of memory and producing imagery. The primary evolutionary advantage of such a system would be to enable conscious animals to quickly process and store information from the environment and others without the need for long training by trial and error. This ties in neatly with the link between consciousness and memory - while we are able to recall the events of our conscious life, we retain no memory of events that occur when we are in a state of unconsciousness, i.e., sleep-walking, hypnosis, anaesthesia, or even when we perform routine tasks. This is why we cannot always remember having locked the car or where we put our glasses, as these are things we do automatically, without being conscious of our actions. For the same reason we often have no memory of what we unconsciously saw while driving along a well-known road - we have effectively been on autopilot, without conscious attention.

The second evolutionary advantage for conscious animals is the ability to use mental imagery to make predictions, to create expectations and to solve problems, even in the absence of corresponding environmental stimuli - an enormous boon from an evolutionary perspective. In this regard, Derek Denton⁽²⁰⁾, in his chapter on consciousness in animals, reports the following quotes, which we will also borrow, that advocate the idea that the function of consciousness is precisely to create mental images.

The idea of purpose is an integral part of the concept of mind, and equally the idea of intention. It can be said, I think, that an organism capable of having

intentions possesses a mind [...] to develop a plan and to make a decision, that is to adopt the plan. The idea of developing a plan requires in turn the ability to build an internal model of the world (C. Longuer-Higgins in “The Development of Mind”, 1973)⁽³⁵⁾.

The characteristic feature that defines the intent is to be a property of mental life that refers to any entity which at that moment is not observable. Intentional thoughts are therefore different from other thoughts directed to a purpose, in which the goal is clearly in sight. [...] Trying to give a general definition of intentionality, one could say that it corresponds to the state of the individual planning an action or waiting for it to occur with respect to some situation that is not directly present (J.Z. Young: “Philosophy and the brain”, 1986⁽⁶⁹⁾).

□ HOW CONSCIOUSNESS MAY HAVE EVOLVED

Let us now examine the degree to which the NCCs and their consciousnesses are present on the various rungs of the evolutionary ladder. Here we assume that fish and amphibians are not conscious. It has been shown⁽²⁰⁾ that these animals possess primordial cortices, able to handle, unconsciously, complex motor activities, sensory perception and memory. They also possess an emotional system (amygdala, nucleus accumbens, lateral hypothalamus) able to select between the various external stimuli, and the thalamus as a system of unconscious attention. Such a system is capable of complex learning, an evolutionary leap from the simple food/response pattern of a paramecium, but it is still only effective in the presence of the relevant environmental stimuli. It would not confer the ability to form mental images, and consequently does not indicate the presence of consciousness. From this unconscious basis, evolution, with the appearance of higher-order cortices, would have produced the 8 consciousnesses, enabling conscious beings, as we have seen, to learn and to memorize new knowledge quickly, even after only one experience.

Some of these consciousnesses are already present in reptiles, which have evolved a limbic cortex (anterior cingulate, posterior cingulate-precuneus, and insula) and higher-level sensory neo-cortices⁽⁵¹⁾. Hence, according to our reasoning, reptiles should also possess the corporeal consciousness furnished by the posterior insula, the emotional consciousness of the anterior insula, the object location consciousness of

the superior parietal lobe, and the perceptual consciousness of the superior temporal lobe. This would indicate, hypothetically at least, that these animals possess corporeal, physical, emotional, spatial and semantic memories. Further up the ladder, birds and mammals also have the frontal area BA 8, which drives extrapersonal motor consciousness and gives them the possibility to store memories of movements in space. This would explain why reptiles, birds and mammals are able to solve problems⁽³⁾ that involve the ability to hold mental images⁽²⁰⁾, while fish are not.

The BA 6 appeared for the first time in monkeys, providing peripersonal motor consciousness and memory of hand (or paw) movements. The subjective-motor consciousness of the Author, on the other hand, would not have evolved until the apes (e.g., chimpanzees), the first animals to possess an inferior frontal lobe BA 44-45-46⁽¹⁾. Indeed, the great apes are able to recognize themselves in the mirror - presumably through an ability to compare their current movement with the mental image of that same movement. Therefore, subjective motor consciousness gives a being the feeling of being the Author of what is occurring, enabling episodic memory.

It was not until humans, however, that the subjective consciousness of being a spectator, or reflective self-awareness, evolved, along with the appearance of the inferior parietal lobe BA 39/40⁽⁴⁸⁾. Reflective self-awareness is the perception of body position with respect to where the object is, and it gives us the feeling of being present in the environment. In fact, Povinelli⁽⁵⁰⁾ showed that between man and chimpanzee there are evident differences in cognitive abilities that go beyond the obvious difference in verbal communication. As a matter of fact, chimpanzees are unable to solve experimental problems that require the ability to refer to themselves as subjects of the scene. This self-awareness is thought to be necessary for autobiographical memory and give us the capacity to reflect upon ourselves (meta-consciousness). Through subjective consciousness, we are able to make assumptions about our own future and what other people are thinking. Hence, we have a theory of mind, because we can remember how we behaved in similar situations. The knowledge that the other thinks the same or something similar to ourselves is considered by most Authors to be an assumption of communication through language. Confirmation of the close link between consciousness and language is given by the fact that the areas of language in the left

cerebral hemisphere correspond to Broca's area and Wernicke's area. The former is made up of areas of the inferior frontal lobe and the latter of the superior temporal lobe and inferior parietal lobe⁽⁶⁾ - all areas of the brain that are NCCs of some type of consciousness, at least according to the theory outlined herein.

□ THE MIRROR NEURONS

The hypothesis that the NCCs are active both when they receive an external image and when a mental image is produced immediately brings to mind the mirror neurons studied by Rizzolatti et al.⁽⁵³⁾. These researchers found that, in monkeys, mirror neurons are activated both when an action is executed, and when it is observed being executed by another. The data suggests that these neurons are also present in humans^(36,46), making it possible to speculate on our own ability to understand the actions of others and on how this would have allowed the emergence of sociality, and then language.

In my opinion, these mirror neurons belong to motor consciousness, which, as we have seen, is active when a particular movement is performed consciously and when it is merely imagined. Indeed, it has been demonstrated experimentally that mirror neurons are activated not only when you execute and observe a movement, but even when you imagine yourself making this movement⁽²²⁾. Hence we can assume that when a monkey sees a movement accomplished, it creates a mental image of the same movement, as performed by itself.

Intriguingly, there is a surprising anatomical overlap between the proposed NCCs and areas considered part of the mirror neuron circuit⁽⁷⁾, which would lend weight to the theory that the mirror neurons studied by Rizzolatti and staff⁽⁵³⁾ are in fact the neurons of motor consciousness and the other 7 consciousnesses (which of course are activated simultaneously). Going one step further, we could call the NCCs of the 8 respective consciousnesses the mirror neurons of the corporeal emotional, perceptual, positional and subjective spectator consciousnesses, and the 3 motor consciousnesses.

□ CONCLUSIONS

As we have seen, the NCCs have been specifically identified one by one by the characteristic neglect

caused by lesions in each area of the brain responsible for a particular consciousness, and by the fact that bilateral lesion each area completely prevents it from exerting its specific function (without affecting the other consciousnesses). What is more, fMRI studies confirm that these areas are active while carrying out the function that is severely impaired by their respective specific neglect and during conscious perception, and the same areas are damaged in Alzheimer's disease, which causes a loss of conscious autonomy.

As Damasio⁽¹⁴⁾ suggested, there appear to be brain areas related to consciousness that act as points of convergence of both the image of the object and the emotions (or memory of the emotions) generated by the object. This idea, which may not necessarily be confined to emotional consciousness, seems to mesh neatly with the concept of mirror neurons, which may enable conscious animals, ourselves included, to build mental images or representations, an evolutionary advantage in terms of rapid learning and problem-solving by image-based reasoning.

Although we will never know what animals think, confirmation of the above may enable us to state that reptiles, birds and mammals are aware of their body and a sequence of meaningful images, but they are not aware of being the doers those actions. Monkeys, on the other hand, are aware of making certain movements, but they have no subject consciousness of themselves as the Authors of such action, unlike the apes, in whom this awareness has evolved. According to this theory, however, it is we who stand alone, conscious of our subject spectator status in the Theatre of Consciousness.

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