Review Paper

International Physiology
Vol. 4 No. 2, July - December 2016
DOI: https://dx.doi.org/10.21088/ip.2347.1506.4216.7

The Mirror Neuron System: Basic Concepts

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Abstract

About two decades ago, it was discovered that some neurons in F5 area of ventral premotor cortex of the macaques monkeys discharged not only when the monkeys performed a motor act, but also when they saw the same act being done by another monkey. The accidental discovery of these fascinating neurons, named the *Mirror Neurons*, urged the scientists to think of presence of such kind of neurons in humans because the same area, the premotor cortex, exists in the human brain. In this article, we review first the basic properties of these neurons in monkeys. We then describe the Mirror Neuron System (MNS) in humans; we also compare the MNS of monkeys with that of humans. The aim of this review is to provide an account of the basic concepts &functionalproperties of the system formed by mirror neurons.

Keywords: Mirror Neurons; Imitation; Action Understanding.

In the mid-1990s, scientists studying the grasp response of macaques monkeys found that certain neurons in the area F5 of theirventral premotor cortex, sent out action potentials not only when the monkeys were moving their hands or mouths, but also when they were simply watching another animal or a human being who was making such a gesture [1-3].

These neurons were appropriately named mirror neurons because plausibly an observed movement was being 'mirrored' in the motor representation of the same movement in the observer.

Subsequent research elucidated the diverse regions, other than area F5, to be involved in the Mirror Neuron System (MNS) of monkeys as well as humans.

Basic Properties of Monkey Mirror Neurons

There are two classes of visuomotor neurons in monkey area F5:-

1. *Canonical neurons,* which respond to the presentation of an object [4]. Theybecome activated when the animal merely sees an object that can be grasped by the prehensile movement of the hand. The main property of canonical neurons is thus, to match the shape and size of the observed object with a specific type of prehension, as if the brain were foreseeing a possible interaction with this object and preparing itself accordingly.
2. *Mirror neurons*, which respond when the monkey sees object-directed action[5]i.e. which are activated both when they perform an action as well as when they see someone else performing it.In order to be triggered by visual stimuli, mirror neurons require an interaction between a biological effector (hand or mouth) and an object.

The characteristic property of mirror neurons is therefore, that of matching observation of hand and mouth motor acts with the execution of the same or similar motor acts. This matching mechanism enables the observing individual to achieve an automatic understanding—i.e. anunderstanding without inferential processing of others' goal-directed motor acts [6].

These mirror neurons are *not* activated with the mere sight of an object, of an agent mimicking an action, or of an individual making intransitive gestures that are non-object-directed. Also, the mirror-neuron response does not depend upon object significance for the monkey; grasping a piece of food

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or a piece of wood produces the responses of the same intensity.The discharge is of the similar intensity even if the experimenter grasps the food and gives it to the recorded monkey (reward)or to another monkey introduced in the experimental room.

Virtually all mirror neurons show compatibility between the visual actions they respond to and the motor responses they code [2].The main feature of the visual properties of mirror neurons in both premotor and parietal cortices is the congruence between the executed and the observed motor act [1,2,7]. Although, the visual features of the observed actions are fundamental to trigger mirror neurons, their role is just that they allow the understanding of the observed actions. If action comprehension is possible on another basis (e.g., action sound), mirror neurons signal the action, even in the absence of visual stimuli.

Neurons responding to the observation of actions done by others are not restricted in area F5 in monkeys. Another region in which neurons with these attributes have been described is the superior temporal sulcus (STS) [8,9]. Another cortical area where there is presence of neurons that respond to the observation ofactions done by other individuals is area 7b formingthe rostral part of the inferior parietal lobule [10].

It is interesting to note that in contrast to F5, the mirror neurons of STS do not possess motor properties.

Functions of the Mirror Neurons in the Monkeys

The main function of mirror neurons in monkeys seem to be "Action Understanding". Every time an animal watches an action done by another animal, the neurons that represent that action are activated in the observer's premotor cortex. This unconsious motor representation of the observed action corresponds to that which is spontaneously generated during active action and whose outcome is known to the acting individual. It is thus postulated that the mirror system transforms visual information into knowledge [11].

It is now well established that these neurons code the 'goal' of the motor acts [12,13] i.e. they are directed towards goal and not the movement. Evidence supporting this point is provided by fact that the same neurons discharge when the monkey grasps an object (e.g. food) with its right hand, left hand and the mouth[14]. It is clear that this type of neural behavior cannot be explained in terms of movements because the movement differs in all the three mentioned acts, but the goal is same – eating food.

Basic Properties of Mirror Neurons in Humans

Brain imaging studies reveal that action observation in humans activates the inferior frontal gyrus (IFG), lower part of the precentral gyrus, the rostral part of the IPL and also the temporal, occipital and parietalvisual areas [2]. The frontal and the parietal mirror neuron regions are somatotopically organized. The activation of pars opercularis of the IFG reflects the observation of distal hand and mouth actions, whereas the activation of the premotor cortex reflects proximal arm and neck movements. Unlike those in monkeys, the mirror neurons in humans, fire even while observing meaningless (intransitive) movements. The observation of transitive actions causes the firing of the frontal and the temporal nodes ofthe MNS while that of intransitive actions result in the firing of the frontal node only [15,16]. Another important difference noted was that human mirror-neuron systems code also for the movements forming an action and not only for action (goal) as monkey mirror-neuron systems do. These properties of the human mirror-neuron system are proposed to play an important role in determining the humans' capacity to imitate others' action.

Functions of Mirror Neurons in Humans

Neurophysiological experiments like Electroencephalography (EEG), Functional Magnetic Resonance Imaging (fMRI), Transcranial magnetic stimulation (TMS) etc. demonstrate that when individuals observe an action done by another individual, their motor cortex becomes active even in the absence of any overt motor activity. A first evidence of this was provided in the 1950s by Gastaut et al [17,18]. They observed that the desynchronization of an EEG rhythm recorded from central derivations (the so-called mu rhythm) occurs not only during activemovements of studied subjects, but also when the subjects observed actions done by others.This observation was confirmed by Cochin et al. using EEG recordings [19,20].

Action Understanding

One of the first hypotheses forwarded about the plausible role of mirror neurons in humans was that they enable an individual to understand another's actions. We understand our own actions quite well, so it is logical to suppose that if the same neurons fire when we see someone else perform a similar action, the firing of these neurons tells us what this individual is doing. And this is indeed one of the most widespread interpretations of the function of mirror neurons.

Action understanding is the fundamental function of the MNS in humans too. Each time the individual observes a certain action being performed by another, the mirror neurons representing the performance of that action are activated. The mirror neurons transform visual observation into knowledge [21]. One such possible function was proposed by Mahon and Caramazza (2008): that mirror neurons may provide a sensorimotor enrichment for certain abstract concepts, such as playing a saxophone or dancing a particular dance [22]. As a result of this enrichment mechanism, someone who plays this instrument or dances the dance in which he is adept, could more readily judge someone else's skill by watching them do so, whereas a non-musician or non-dancer would have more trouble in making this judgment.

Imitation

Imitation is the advanced skill seen in primates. The properties of the human mirror-neuron system of responding to not only the goal but the whole movement of the action (goal), are thought to play an important role in determining the humans' capacity to imitate others' action [23].

Basic circuit underlying imitation coincides with that which is active during action observation. Imitation requires a perfect matching of the performed action onto the observed one. Mirror neurons are able torecognize the actions of others and the intention associated with them. So they can code for likely future actions of others, thereby observers are able to anticipate the actions of others [1,23]. Children are thought to learn by imitating their elders. The data indicate that mirror system is adaptive and may start to function as early as 6 months post-birth, although at a rudimentary level [24].

Speech & Language

The mirror neurons are present in Broca's area of humans, which suggests that human language may have evolved from a gesture performance/ understanding system. Broca's area is considered to be a homologous region of vental premotor cortex of monkeys [2]. The tasks like spontaneous speech and reading activate the hand motor area and the IFG, on the left side [25,26]. So language mirror neurons seem to be lateralized to the left side involving the categorical motor cortex and the higher levels of language network; the areas of which are supposedly located on the left cerebral cortex [27].

Empathy

Empathy is the experience of understanding another person's condition from their perspective, i. e. placing oneself in other's shoes and feel what they are feeling. Empathy is known to increase pro-social (helping) behaviors, affective sharing between self and others, adopting the perspective of others and the ability for self agency and self regulation [28].

Theory of mind, Social behavior, communication are other aspects where mirror neurons have a possible role.Social communication and identification involve imitation. The more the people tend to imitate each other, the more they are able to communicate, understand and develop an empathic relationship with each other [23].

Several of researchers in cognitive neuroscience consider that mirror system provides the physiological mechanism for the perception/action coupling, for understanding the actions of other people, and for learning new skills by imitation.Some researchers speculate that mirror systems contribute to understanding of theory of mind, language and empathy and even the intentions of other people [29].

However, in an article published in 2009, Gregory Hickok stirred up considerable controversy by showing that this theory of "action understanding" was poorly supported by the experimental data as most of the research on these neurons has been conducted in monkeys [30]. In a 2013 article for Wired Christian Jarrett also expressed skepticism about the theories being advanced to explain the function of mirror neurons.

To conclude, the fascinating discovery of MNS has generated tremendous enthusiasm among researchers in cognitive neuroscience, but there are mysteries yet to be resolved.

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