

**Review Article**

Mirror Neurons: Fire to Inspire

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Abstract: Mirror neurons got a great deal of attention from connoisseurs and in scientific reports. Mirror neurons have the capability of observation and execution of action to code both “my action and your action”. Firstly they were found in an area of f5 region of ventral premotor cortex and inferior parietal lobule of monkey brain. Mirror neuron system (MNS) is the driving force behind the great leap forward in human evolution. Both monkeys and human are born with MNS. Sensory or motor experience may trigger the development of mirror neurons. Adult group show an intrinsic difference between goal directed and non –goal directed action observation condition. Recently neurons with mirror characteristics have been found outside the rostral part of inferior parietal lobule and inferior frontal gyrus. Human neuroimaging experiments confirm a wide overlap between cortical areas in human and areas where mirror neurons have been reported in macaque monkey. Still there is a lack of studies about MNS in neurosurgical patients so the goal is to describe the application of an fMRI protocol to identify the MNS in patient with mass lesion in premotor area. The goal of this review was to give a brief explanation of MNS covering their origin, observation, execution, innateness, evolution, development, empathy and recent developments like fMRI, neuroimaging and mapping.

Keywords: MNS, BOLD, fMRI, PMC, TMS, IPL, Motor Cortex, EEG, LFP

1. Introduction

Mirror neurons (MNs) found in 1992 and given their incredible name. Mirror neurons initially found in f5 region premotor cortex (PMC) (di Pellegrino et al. 1992; Gallese et al. 1996) and inferior parietal lobule (IPL) (Bonini et al. 2010) of monkey’s brain. They have capability to compare perception and execution of activities to code both “My actions” and “your actions”. Currently, evidences are found showing the presence of mirror neurons (MNs) in human brain (Molenberghs et al. 2012). MNs got a lot of attention from authorities, investigators (scientific research) and public media and are entitled as “cells that read minds” (Blakesee 2006), “neuron that shaped civilization” (Ramachandran 2009), and a “revolution” suggesting social behaviors (Iacoboni 2008). Scientist found that MNs are contributing in many functions. They are essential partners to understand activities, impersonation and dialect processing (Gallese &

Sinigaglia 2011) However, elaborating how MNs becomes the center of attraction of neurologist, psychologist, and philosopher, by their application in embodied simulation, empathy (Avenanti et al. 2005), emotions recognition (Enticott et al. 2008), acceptance-reading (Iacoboni et al. 2005), language accession (Theoret & Pascual-Leone 2002), language evolution (Arbib 2005), verbal communication speech perception and production, sign language, music processing and aesthetic experience (Cinzia & Gallese 2009). Sexual adaptation (Ponseti et al. 2006), and creative experience. Additionally, it has reported that number of disorder occurs due to MNs dysfunction including autism, schizophrenia, down’s syndrome (Virji-Babul et al. 2008), multiple sclerosis (Rocca et al. 2008), cigarette addiction (Pineda & Oberman 2006), and obesity (Cohen 2008).

2. Origination and Execution of Actions

In many discussion of mirror neurons the hypothesis show that mirror neurons help to understand the behavior of other individuals therefore they were selected by natural selection (Rizzolatti and Arbib, 1998; Rizzolatti and Craighero, 2004). According to this hypothesis, mirror neurons are present both in humans and monkeys by birth and have minor role in their development. Sensory or motor experience play a significant role in the development of mirror neurons in their compatibility with executed actions that are genetically inherited.

3. Evolution of the Language-Ready Brain

Mirror system hypothesis (MSH) developed over the years. Hypothesis postulates the stages in biological evolution of brain as it develops from mirror system for manual action of last common ancestor monkeys which enable us to detect more fine action to their abilities in other neural circuits and last common ancestors including the chimpanzees for imitation of action developed a neural capability. According to MSH, our ancestors (but not those of other apes) developed brain mechanisms that supports the ability to recognize others performance and complex imitation mechanisms to approximate the performance with the increasing skill. Studies recommended that brain supporting complex imitation started from oldowan and completed during the late Acheulean. fMRI studies showed the significant role of cerebrocerebellar communication loops in representation of internal models of various tools and lateral parts of cerebellum are involved in this loop. The protolanguage way revived on biological selection in accordance with MSH, while variation in human genome did not require emanation of language from protolanguage but cultural evolution which is rested on millennium. The part of brain for protolanguage ability revived on further three changes in the mirror system. Exapting convoluted action recognition for communication firstly supported pantomime. The significant point here is that this supported the change from communicative gestures to an open ended semantics. The only problem with pantomime is that it is expensive and difficult to filter. This made the versatile weight for the advancement of cerebrum structures to bolster early types of protosign, a manual correspondence framework situated on portion of conventionalization of pantomime to create open-ended semantics. MSH conjectured that protospeech rested on 'invasion' of vocal tool by collateral from communication system, explaining the fact that animals lack vocal control and are unable to produce sound like human. Language ready brain expands on the emergence of protospeech and protosign biological bases. Some theories conjectured that vocal control comes first(much as birds and whales have "song" without words) and later semantic (C. Darwin, 1871 ;W.T. Fitch,2010;S. Mithen,2005).

4. Development of Mirror Neurons

Response of MNs is innate. Human show muscle specific responses to TMS over motor cortex during execution of action. Particular muscle involve in observation of an action elicit a stronger response as compared to incongruent action observation (L. Fadiga et al., 2004). Generally human MNs system is associated with this response. In the whole life of organism visual stimuli is experienced which is created by motor execution. It confirms that both monkeys and human have plastic nature of MNs. This view comes from the idea that mirror neurons and imitation have direct link with the logic that imitation in infant is because of MNs. In human adult EEG markers for the activity of MNs is taken as limitation in mu frequency band (8-13Hz) over motor areas. High amplitude oscillation is shown by mu frequency band because of synchronized firing of neurons but during action and observes movement performed by the subjects the power of mu band show variation because of desynchronization. Mentioned studies reported the decrease in mu frequency during observation and functioning of MNs in 6 months infant and in older infants.

Researcher used transcranial magnetic stimulation (TMS) and functional magnetic resonance imaging (fMRI) interpreted in their research and act as an evidence that human also have broad mirror neuron system. TMS study show that activation of muscles leads to the observed movement of arm, hand and finger. Experiments on fMRI showed that cortical areas activated by (1)actions that do not have visual feedback and (2) similar actions that observed passively and found that they overlap in that area where neurons found in monkeys This evidence indicating overlap at the individual voxels level (Gazzola and Keysers, 2009), and cross modal repetition suppression in inferior frontal gyrus and inferior parietal lobe. For example, blood oxygen level dependent (BOLD) responses to action similarly as relative to dissimilar actions.

5. Innateness Still Under Investigation

Significant difference between goal directed and non-goal directed action conditions is shown by infants. Desynchronization pattern shown by infants are same as adult between conditions. For observing moving dot the immaturity of infants MNs system activation found in infants in contrast for observing static dot which was absent in adults. This showed that mirror neurons start functioning as early as 6 months post-birth. However, innateness still un-answered as to develop in critical phase of 2-6 months the infant MNS system have plenty of data where they learn to grasp. Along with the development of skills (e.g holding) mirror neuron system develop MNs system differs greatly for different actions like facial expressions are not open to self-observation.

6. Action Understanding

MNS in humans consist of the rostral portion in inferior

parietal lobule, the lower portion of the precentral gyrus and posterior of the inferior frontal gyrus (Rizzolatti & Craighero, 2004). Although currently mirror neurons are found in medial frontal and temporal cortex outside the prescribed regions (Mukamel et al., 2010). This mirroring of mirror neuron system amplifies the understanding of goals, actions and emulations (Iacoboni et al., 2005; Rizzolatti et al., 2001). MNS is still unknown but generally the observed actions are delineated to motor representations of the observer's personal actions. This process is considered to be direct i.e. the representation of mirror neurons by direct coupling, activation and association rather than by involvement of higher inferential or other processes. As, Rizzolatti and Craighero state: "the proposed mechanism is rather simple. Each time an individual sees an action done by another individual, neurons that represent that action are activated in the observer's premotor cortex.... Thus, the mirror system transforms visual information into knowledge" (2004, p. 172) as shown in Fig 1. It is stated that this system represents the actions and means of actions (Buccino et al., 2004a; Fadiga, Craighero, & Olivier, 2005), but in contrary to this MNS are also claimed to represent intentions of actions (Iacoboni, 2008; Iacoboni et al., 2005). Like, Rizzolatti & Sinigaglia stated "through matching the goal of the observed motor act with a motor act that has the same goal, the observer is able to understand what the agent is doing"

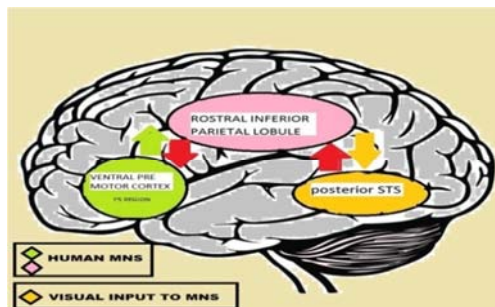


Fig. 1. Mechanism of Mirror Neuron System.

7. Empathy and MNS in the Vision of Psychology and Neuroscience

This action understanding, immitationing, mentalising, perceiving the intentions of actions and mirroring is empathy; complex phenomenon that includes understanding of intentions by different processes. In the view if psychology and neurosciences some distinctions are mentioned in understanding other's intentions of actions. Recently this distinction that depends upon fundamental distinction is proposed by number of authors in decision making domain (Sloman, 1996), that is distinction in system 1 and system 2. System 1 (Stanovich & West, 2000) also called intuitive, experiential (Slovic, Finucane, Peters, & MacGregor, 2002), impression-based (Kahneman, 2003) is fast and unintentionally triggered with rigid functioning beyond indivisual control normally operating without effort based association. System 2 also labelled analytical (Slovic et al.,

2002), judgment-based (Kahneman, 2003), deliberative (Hogarth, 2001) and rational (Epstein, 1994) that performs purposely, steadily, intentionally and supremely on the basis of logical rules and abstract representations. This system is not changed emotionally but fails to work properly because of requirement of high cognitive load and high amount of energy and effort for its activation. In this aspect difference between type 1 and type 2 was proposed by (Bohl and van den Bos (2012) specific to social cognition. The former is rigid, efficient, fast, and stimulus driven and the latter is elaborative and showing high cognitive load and consciously approachable (Waytz and Mitchell (2011) in a very restricted way to understand other people's intentions distinguished two mechanisms 1) mirroring 2) self-projection. Mirroring the first mechanism mirrors the other people's mental state in our minds that help us in understanding by experience. In self-projection we impute our mental states on the other to influence their mental states. Both the mechanisms have different level of awareness. Mirroring an online process make us capable of feeling others experience by comparison and self-projection; it is an offline imagination that make us feel the experience like if we were in others shoe or in their conditions. The distinction of mentalising and mirroring overlaps in difference between mirroring and self-projection. (Chiavarino, Apperly, & Humphreys, 2012).

8. Human Neuroimaging Data

After studying all the different aspects of mirror neurons and mirror neuron system now the recently aspect under study is human neuroimaging data. The results specifically in fMRI (Molenberghs et al., 2010) in human neuroimaging showed an overlap between the areas that are active during action observations i.e. cortical areas and the same areas in macaque monkey where mirror neurons have been previously reported. Thus fluctuations, in BOLD signals during observation of actions are consistent because of MNS present in humans. However a single neuron activity in neurosurgical patients showing mirror activity has been reported (Mukamel et al., 2010). Monkey's fMRI studies showed the activity of MNS during action observation that is also now under study for humans (Nelissen et al., 2005; Peeters et al., 2009). These imaging are beneficial for boosting iron-based (MION) contrast agent neurovascular responses. The only problem in relating these results to MNS is that they only show action observation and have no action execution characteristic. The possible attribution to single neuronal population like MNS is to use neuroimaging tool that the fMRI adaptation that will help to identify neural populations encoding particular stimulus (Grill-Spector et al., 2006). The reason for fMRI adaptation is that the repeated presentations of stimulus causes reduction in neurons firing rate, this repeated presentations will also cause BOLD signals to reduce. The features that MNs in the cortex region should show both the observation and execution of action, because in MNS encoded stimulus feature is repeated regardless, of the action observed (Dinstein, et al., 2007). The results are mixed like three out of five

studies have showed fMRI adaptation in MNS of humans (Kilner *et al.*, 2009; Press *et al.*, 2012). A single reason for the mixed result is that MNs are present in humans but they don't change their activation pattern and repetition of stimulus. Indeed recent research has shown evidence that these MNs don't change their firing rate on the repetition of same actions through the activity of neurons in local field potential (LFP) changed with repetition (Caggiano *et al.* 2013). Although research is required to learn why MNs don't change but LFP and BOLD signals change with repetition in humans. Studies in human and monkeys should be compared carefully. Majority of Human neuroimaging studies reported that about 30% of neurons changed during action observation and execution but it doesn't mean 70% remain unchanged; this 70% region is still under study but has not showed any evidence for showing MNs activity. Literature review made it clear that MNS firing activity is triggered by visual stimulus (Caggiano *et al.*, 2011) and are also activated by other inputs rather than visuals(e.g. auditory) (Umiltà *et al.*, 2001)

9. Conclusion

MNS is a network in a brain that gets activated during observation and then execution of observed actions but no one ever gave attention to map these neurons. To solve the above mentioned complex riddles of MNS Brain mapping is an essential and important neurosurgical technique to understand the functional outcomes. fMRI is also a preoperative brain mapping that has mapped many brain functions like language, cognitions, emotions and other motor related conditions. MNS occupies the major portion of brain including parietal region (inferior parietal lobule, superior parietal lobule and intraparietal sulcus) and frontal region (ventral, dorsal premotor cortex and inferior frontal gyrus). Damage to MNS can cause severe cognitive disorders. fMRI is considered to be an appropriate method to study the extensive network of MNS. MNS is completely explained till now as they are under study. Assumptions from monkey studies that mirror neuron system is also present in human have not enough data till now and supported by indirect evidences e.g. TMS etc.

Abbreviations

MNS(Mirror Neuron System), BOLD(Blood–Oxygen-Level Dependent), fMRI (functional Magnetic Resonance Imaging), IPL(Inferior Parietal Lobule), TMS (Transcranial Magnetic Stimulation), PMC(Premotor Cortex), LFP(Local Field Potential), EEG(Electroencephalogram).

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