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REVIEW ARTICLE

MIRROR NEURONS – DISCOVERY, SIGNIFICANCE AND ROLE IN SOCIAL COGNITION

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ABSTRACT

Objective: To review the literature for evidence based understanding of mirror neurons, its discovery, and significance in social cognition.

Background: Mirror neurons are a type of brain cell that respond when we perform an action and when we witness someone else perform the same action. They possess the fascinating property of being activated by the performance as well as the observation of specific motor actions. It is widely assumed that mirror neurons were designed by evolution to enable action understanding. That is, the neuron "mirrors" the behavior of the other, as though the observer was acting. It was first discovered in the ventral premotor cortex (area 5) of the monkey (*Rhesus macaque*). Recent research has discovered these neurons invarious parts of the human brain including the somatosensory cortex. These areas are thought to make the observer feel what it's like to move in the observed manner. Mirror neurons play an important role in understanding the actions of other people, and for learning new skills by imitation. It is believed to play a role in various aspects of cognition, observed action, mind skills, and language abilities.

Design: A systematic review of original research papers investigating mirror neuron systems in humans and its effect in social cognition like imitation, language, emotion, empathy and learning was conducted. Literature was sourced from articles and reviews in PubMed.

Results and Conclusions: Mirror neurons play a significant role in intentional thought, subsequent action and interpretation in a person as well as that of others. Social interaction may have a neuroscientific basis although more research is needed to evaluate the underlying mechanisms involved.

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INTRODUCTION

It has been argued that interaction with members of one's own social group enhances cognitive development in primates and humans[1,2,3]. For years, such experiences have puzzled psychologists, neuroscientists and philosophers. Why do we react to other people's actions? How do we understand, so immediately and instinctively, their thoughts, feelings and intentions? The discovery of mirror neurons might provide a neuroscientific answer to these questions. It expands the clarifying scope and experimental base for simulation as a necessary component of social behavior. Prior to the discovery of mirror neurons, it was believed that the fundamental process of cognitive processing was the use of one's own cognitive resources in order to simulate another's mind. However post discovery arguments believe that "mirroring" may constitute instances of mental simulation[4,5]. This has revolutionized our understanding of social behaviour as it is claimed to be "the driving force behind 'the great leap forward' in human evolution.''[6]. Mirror neurons were originally defined as neurons which ''discharged both during a monkey's active movements and when the monkey observed meaningful hand movements made by the experimenter''[7] Mirror neurons are a type of brain cell that respond equally when we perform an action and when we witness someone else perform the same action. They possess the fascinating property of being activated by both the performance as well as the observation of specific motor actions. Neurons with this capacity to match observed and executed actions, can code both 'my action' and 'your action'[8]. V.S. Ramachandran has called the discovery of mirror neurons one of the "single most important unpublicized stories of the decade" [9]. Since its discovery in 1992, many theories have evolved about mirror neurons making it "the most hyped concept in neuroscience''[10]. This article aims at reviewing this fascinating concept that may hold the key to understanding the human mind and its several processes.

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Discovery in Rhesus Monkey

GiacomoRizzolatti *et al*. in the early 1990s, first identified these neurons and named them "mirror neurons"[6]. They discovered individual neurons in the brains of macaque monkeys that fired when monkeys grabbed an object and also when they watched another primate grab the same object. These neurons were located in the ventral premotor cortexarea 5 [11][12]. Evidence now suggests that mirror neurons (MNs) are present throughout the motor system, including ventral and dorsal premotor cortices and primary motor cortex, as well as being present in various regions of the parietal cortex and the inferior parietal lobule (IPL) of the monkey brain[13, 14].

Discovery in Humans

Substantial evidence shows that MNs are also present in the human brain[15]. A study by Mukamel *et al*., in 2010 [16] presented direct evidence, from single cell recording of MNs in the human brain. There is proof that supports the presence of single neurons, or segregated populations of neurons, with sensorimotor matching properties in classical areas of the human brain, including posterior regions of the inferior frontal gyrus (IFG). This area is considered the human homologue of the area 5 cortex in the Rhesus macaque[17]. Other areas include the inferior parietal cortex[18] and non-classical areas of the human brain, the dorsal PMC, superior parietal lobule, cerebellum[15], supplementary motor area, and medial temporal lobe[19.] Functional magnetic resonance imaging (fMRI) suggests that a much wider network may be involved in "mirroring" properties in the human brain [20, 21] Indirect evidence from neuroimaging, transcranial magnetic stimulation (TMS), and behavioral studies show the existence of MNs or comparable 'mirror mechanisms', which respond during both action and observation of action in the human brain[2].

Pathogenesis

Eye-tracking measures of infants suggest development of the mirror neuron system before 12 months of age[23]. Champoux *et al*[24]address the critical issue of the developmental trajectory of mirror neurons and argue that motor behaviors in utero may serve as building blocks for the appearance of the MNs. The most widespread theory behind the origin of mirror neurons is the genetic hypothesis. Other theories like associative learning, canalization and exaptation also attempt to explain the origin of these "mind mirrors" [25].

Genetic hypothesis

According to this hypothesis, gene-based natural selection has provided each individual – monkey and human - with MNs that code the mapping between a fixed set of observed and executed actions, and that knowledge plays a role in the development of the observation-execution matching properties of these neurons. Gallese *et al*. (2009) [26]suggested the formation of links, during gestation, between motor regions and "to-become-visual" regions. These then mediate sensorimotor matching abilities in infants. They suggested that these projections are genetically predisposed to target certain visual areas, and that the matching properties of MNs are produced by data programmed in the genome.

Associative Learning Hypothesis

Hebbian [27] or Associative learning are models that propose the "mirroring" attribute of these neurons [28, 29, 30]. Keysers and Gazzola [31] describe a neurophysiological mechanism involving Hebbian learning that can account for the shared representations of mirror neurons. It implies that the characteristic matching properties of MNs result from a genetically evolved process, associative learning, but this progression is not 'designed' by genetic evolution to produce MNs. Rather, when the developing system receives correlated experience of observing and executing similar actions it processes MNs. When the system receives correlated experience of observing objects and executing actions, the same associative process produces canonical neurons. When the system receives correlated experience of observing one action and executing a different action, the same associative process produces logically related MNs.

Neural Exploitation Hypothesis

Gallese[3] proposes the ''neural exploitation hypothesis'' to explain how brain mechanisms mediate aspects of social cognition initially evolved for sensory-motor integration. The neural exploitation hypothesis holds that embodied simulation and the MNs provide the means to share communicative intentions and meaning, thus granting the parity requirements of social communication

Canalization Hypothesis

This is similar to associative learning hypothesis. It Canalization is a measure of the ability of a population to produce the same phenotype regardless of variability of its environment or genotype. It is hypothesized that mirror neurons are canalized as it is believed that their developmental pathways are shaped by evolution. In contrast with the associative hypothesis it affirms that self-observation above social interaction is a source of significant sensor motor experience in development [33].

Expatiation

They propose that MNs are produced, by a particular kind of sensorimotor learning which receives input from self-observation of hand motion [34,35]. This special kind of learning is an "exaptation" for action understanding; it evolved from more domain general mechanisms, such as those producing canonical neurons, specifically to promote action understanding through the production of MNs. It suggests that "some additional structure is required, both to constrain the variables relevant for the system, and to track trajectories of those relevant variables", and that the function of this extra structure is to ensure coding of goals or "hand-object relationships[35]"

Other processes

Semin and Cacioppo[3]view mirroring as a monitoring synchronization process that is only a supportive component of social cognition but that it can occur in at least three different

forms of co-action. Chong andMattingley[18]argue that MNs are open to top-down processes such as cognitive strategy, learned associations and selective attention. Oberman and Ramachandran[37]expand the definition of mirroring as a remapping from one domain into another and hence expand the explanatory power of this process. Similarly, Pineda *et al*[38] extend the definition for mirroring-like processes that occur at all levels of information processing in the central nervous system producing a gradient of faculties that vary in complexity from stimulus enhancement, response facilitation, emotional contagion, mimicry, simulation, and emulation to imitation, empathy, and theory of mind.

Imitative or predictive role?

As MNs are involved in imitation, it leads to a fascinating paradox that although macaque monkeys possess such cells in the premotor areas, there still remains substantial data proving they posses only restricted capacity for imitation. This suggests that mirror neurons may play different functional roles in the two species or may be involved in a unique common role. Current studies show that non-human primates possess the ability of reasoning to the extent of being capable of identifying the intention behind the actions [3,9]. This is consistent with a ‘‘predictive’’ rather than an ‘‘imitative’’ function for mirror neurons. This implies specialized cells may be more concerned in inferring intentionality rather than in imitating actions. Studies at the single cell level provide evidence consistent with this explanation[40,1,3, 41].Furthermore, the existence of ‘‘logically-related cells’’ as compared to ‘‘congruent’’ cells in the inferior frontal gyrus and their ratio in human and non-human primate brains provides a prospective explanation as to why monkeys possess low imitation capacities and higher intentionality and why humans are exceptional at both.

Significance

Mirror neurons have led to a fresh understanding of intentional thought processes and help us discern the generation of our own actions and the interpretation of the actions of others. This discovery has prompted the concept that, action, execution and observation are closely associated processes, and our ability to interpret the actions of others requires the involvement of our own motor system. Mirror neurons have been variously described as the “cells that read minds”[42], “the neurons that shaped civilization”[43]and a “revolution” in understanding social behavior[44].They have been recognized to play an extensive role in social cognition. The role of MN's may be associated with action understanding [45,46], imitation[47],and language processing[48]embodied simulation[49]empathy[50]emotion recognition[51]intention-reading[41], language acquisition[52], language evolution[53], manual communication[46], sign language processing[54], speech perception[55],speech production[51],music processing[57], sexual orientation[58] and aesthetic experience[59]. Intriguing phenomenon like ‘‘chameleon effect’’, which is the unconscious mimicry by the observer of postures, expressions, and behaviors of people around them can find a neurophysiological explanation with the presence of MNs in the human brain[60]. Furthermore, it is believed that MN malfunction can lead to autism[61, 62,63], schizophrenia [64], Down’s syndrome[65], multiple sclerosis[61], nicotine addiction[67] and obesity[63].

Mirroring mechanisms in emotion

Recent brain imagery studies in humans, for example, have revealed that the insula is the brain structure that is active when a person experiences an emotion such as disgust, as well as when the same person perceives another person experiencing disgust. This supports the notion of a ‘‘mirroring’’ theory of social cognition, according to which the basis of human social cognition would be provided by a variety of mirroring brain mechanisms.

Understanding intentions behind actions

MNs are believed to explain how we predict the goals or intentions of a person by just watching only one part of the activity. The activity of neurons in the IPL has been recorded. In this experiment, monkeys watched an experimenter either grasp an apple and bring it to his mouth or grasp an object and place it in a cup[14].It is believed from the conclusions of this study that only the nature of action, and not the kinematic force with which the subject manipulates the objects, determined neuron activity. Neurons fired prior to the observation of the second motor act (bringing the object to the mouth or placing it in a cup). Hence, IPL neurons "code the same act (grasping) in a different way according to the final goal of the action in which the act is embedded"[14]. This offers a neural basis for predicting another individual’s succeeding actions and understanding intention[14].

Language

Our understanding of the meaning of a word like ‘‘table’’ does not stem from our use of a linguistic game, which, at best, can specify when to apply a given word as a tag to a given object in the world. The meaning of ‘‘table’’ stems from its use, from what we can do with it, that is, from the multiple and interrelated possibilities for action it evokes [69,70]. Homologous to the monkey mirror neuron system in the inferior frontal cortex, Brocas region claimed as the language center of the brain is associated with MN in the nearby regions. Brain activity of two participants playing a game of charades was measured using fMRI. Analysis revealed that the mirror-neuron system of the observer reflects the pattern of activity in the motor system of the sender, supporting the idea that the motor concept associated with the words is indeed transmitted from one brain to another using the mirror system[70]. When we speak, by means of the shared neural networks activated by embodied simulation, we experience the presence of others in ourselves and of ourselves in others. Hence “mirroring” bridges the gap. McGuigan and Dollins (1989)[71] also used EMG to show that tongue and lip muscles are activated in covert speech in the same way as during overt speech.

Gender differences

Studies conducted by Yawei Cheng, have documented the presence of a gender difference in the human mirror neuron system, with female participants exhibiting stronger motor

resonance than male participants[72-75]. In another study, gender differences among mirror neuron mechanisms showed enhanced empathetic ability in female in contrast to male participants. This may be due to the fact men have limited emotional expression as it has been practiced in most cultures.. However, when it came to recognizing the emotions of others, all participants' abilities were very similar and there was no key difference along a gender binary[76].

Limitations and future scope

The functional role of mirror neurons, although researched, still requires extensive study to provide a better understanding of their specialized properties in the various processes of social cognition. Whether mirror neurons arise as a result of a functional adaptation and/or of associative learning during development are important questions that still remain to be answered. We need a better understanding of their links to other neuronal systems and their integrated role in socio-biological function and interaction.

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