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Mirror Neurons and Their Reflections

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Abstract

Human mirror neuron system is believed to provide the basic mechanism for social cognition. Mirror neurons were first discovered in 1990s in the premotor area (F5) of macaque monkeys. Besides the premotor area, mirror neuron systems, having different functions depending on their locations, are found in various cortical areas. In addition, the importance of cingulate cortex in mother-infant relationship is clearly emphasized in the literature. Functional magnetic resonance imaging, electroencephalography, transcortical magnetic stimulation are the modalities used to evaluate the, activity of mirror neurons; for instance, mu wave suppression in electroencephalography recordings is considered as an evidence of mirror neuron activity. Mirror neurons have very important functions such as language processing, comprehension, learning, social interaction and empathy. For example, autistic individuals have less mirror neuron activity; therefore, it is thought that they have less ability of empathy. Responses of mirror neurons to object-directed and non-object directed actions are different and non-object directed action is required for the activation of mirror neurons. Previous researchers find significantly more suppression during the observation of object-directed movements as compared to mimed actions.

Keywords

Mirror Neuron, Mirroring, Empathy, Mu Suppression

Subject Areas: Neuroscience

1. Mirror Neuron System Activity in Humans

Mirror neurons are stimulated both when an action is performed and/or observed. Cells in the human brain mediate action understanding, imitation, and intention/emotion understanding [1].

Neurophysiological experiments performed by using electroencephalography (EEG), magnetoencephalography and functional magnetic resonance imaging (fMRI), have demonstrated that the motor cortex of an observer not engaged in any motor activity is activated during the observation of motor movements performed by other individuals [2]-[4].

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2. Location and Function of the Mirror Neuron System

Mirror neuron systems, located in the premotor area and in various parts of the cortex, have different functions according to their location. Mirror neurons at posterior parietal and premotor area are important in understanding the goal and intention of the observed action [5]. Broca's area is the part of the brain that is involved in generating speech [6].

Mirror neurons found in the inferior frontal gyrus (region F5) and in the inferior parietal lobule of macaque monkeys [7] were shown to have important roles. The brain electrical activity of macaque monkeys recorded during observing a human who is imitating the mouth movements of the monkeys used for social interaction (lip protrusion, smacking etc.), revealed that they were mirroring human's jests and mimics [8]. Researchers from Parma University showed that on observation of a person grasping a box, the brain activity of macaque monkeys at the same area changed as if they were grasping a box even if they were not acting [5] [9] [10]. Additionally, mirror neurons in the F5 area of monkeys were found to be activated not only when they were performing goal directed actions (grasping, holding, tearing, and breaking objects with hand or mouth) or observing someone executing those actions, but also by visual or verbal stimulus triggering them. Research results revealed that mirror neurons in the premotor area respond to both visual perception and sound of actions (such as the sound of a peanut cracking) [11], but "canonical neurons" respond to the visual presentation of objects (such as a visually presented peanut) [11] [12].

Mu frequency suppression in EEG recordings (alpha and low beta; 8 - 12 Hz and 12 - 20 Hz respectively) over the sensorimotor cortex revealed the existence of mirror neuron activity in the pre-motor cortex [13]. Alpha and beta desynchronization over the sensorimotor and supplementary motor area (SMA) was associated with movement execution [14] [15] and observation [16]. fMRI recordings of humans showed that human mirror neuron system areas were active during performance, observation and imagination of movement [17], during point light biological animations [18] and during presentation of object-directed action sounds [19].

3. Results of the Dysfunction of Mirror Neuron Activity

Mirror neurons have very important functions such as language processing, understanding, learning, social interaction and empathy. Individuals with autism have reduced empathic ability as they have reduced mirror neuron activity [20].

In order to study the effects of social interaction on mirror neuron activity, researchers showed four different videos to the study group: a) an empty white screen; b) (without social activity) three people throwing balls up in the air and grabbing back; c) (with social activity) three people throwing a ball to each other and grabbing it back; and d) (with social activity, interactive) similar to c but sometimes, the ball was thrown towards the screen as if the viewer was also playing. They concluded that social interaction increased the activity of mirror neurons [21].

Oberman *et al*. [20] demonstrated significant mu rhythm desynchronization during action execution (opening and closing the right hand) in both autistic and control children and significantly reduced mu rhythm desynchronization during movement observation (watching a video of a hand opening and closing) in the autistic group compared to the control group [22]. Significantly lower mu power desynchronization in the autistic group during observation of a movement, correlated with poorer skills of facial imitation [23].

Researchers explored the modulation of motor cortex activity by premotor areas, including inferior frontal gyrus by recording event-related desynchronization (ERD) in alpha and lower beta waves during hand movement and static hand observation over motor (C electrodes in the 10 - 20 system) stripe [13] [20] [22].

The network of mirror mechanism involving action-constrained mirror neurons first identified in the inferior parietal lobule of a monkey [24]. These "action-constrained" mirror neurons fire in case of an observed action followed by a specific intention, like eating of a grasped item. However, these neurons do not fire if "grasping" is followed by placing of a grasped item into a container.

The observed motor act triggers the action-constrained mirror neurons, which are activated to achieve the intention of the others. For example, the electromyogram activity of the mylohyoid muscle of an individual increases, when he is asked to reach and grasp a food.

Research results show that autistic individuals have impaired "chain-based mirror mechanism" that cause a deficit in understanding the motor intention of others [25].

Alpha and beta EEG rhythms have been shown to desynchronize over the premotor, primary and somatosensory cortices during the observation and execution of aimless movement [16]. This suggests a deficit in translating observed motor intention, and understanding the reason of an action. It was suggested that SMA translates intentions into actions, which can be shown in premovement beta ERD. Research results show that SMA of normal individuals with low traits of autism is activated (low beta ERD) during observation of goal-directed hand actions but a significantly reduced activity was recorded during the observation of static hands. However, in individuals with high traits of autism, the SMA is activated (low beta ERD) both during observation of goal-directed hand actions and static hands [23].

The mechanism of mirror neuron activation was researched using different types of stimulations to trigger the neuron activity. The difference between the grasping movement of a robotic hand and a human hand on mirror neuron activation, the difference between repeated grasping movements and one grasping movement on mirror neuron activation and the difference in mirror neuron activity during the observation of grasping different objects were evaluated. Additionally, mirror neuron activity changes with movements like grasping a ball and throwing it up in the air, throwing the ball to another person or involving in social interaction, were recorded and evaluated [21] [26] [27].

According to the research results, mu wave suppression that corresponds to mirror neuron activity was mostly recorded in the right hemisphere [27].

4. Gender Differences in Mirror Neuron Activity

Mu wave suppression was observed predominantly in women compared to men at the same experimental condition [26]. Mirror neuron researches showed that live observation of a movement triggers mirror neurons more than watching a video of a movement [28]. However, a study revealed that watching a video of a robot hand grasping an object or a video of a human hand grasping an object had similar effects on mirror neurons and cause similar mu suppression [29]. However, when human hand was moved with the aid of rope like a puppet, mirror neuron activity was found to be reduced. Grasping different objects caused more mu suppression compared to the observation of repeated movement [27]. In addition, mu suppression was found to be significantly increased with social interaction such as grasping a ball and throwing it to someone else [20].

Research results showed that observation of upright point-light walkers activated mirror neurons in the premotor cortex but scrambled biological motion did not, as measured by fMRI [18]. Additionally, it was shown that point-light walkers at inverted position (walking on its hands) did not activate the mirror neurons [30].

5. Mirror Neurons and Empathy

Empathy, which is essential for the regulation of social interactions, allows an individual to quickly and automatically perceive and understand the emotional states of the others [31]. Freud suggested theories about the biological correlates of empathy and established the basis of this modality decades ago [32]. Some other theorists emphasized the importance of empathy in the early years of life regarding the relationship between the mother and child in terms of developmental psychology and investigated its role in psychopathology [33].

Empathy is thought to be evolved in the context of parental care in the mammalian species.

Empathy is also defined as the way to temporarily think and feel like others [34] and it aims to understand others emotionally at an intellectual level [35].

The discovery of the mirror neurons has played an important role in understanding the biological origins of empathy. In a study on species-typical empathy, it has been shown that watching a human yawning created a yawn response in 21 out of 29 dogs but mouth opening actions without yawning movement pretending to yawn produced no yawn response [29].

Harrison *et al*. [36] investigated the effects of pupillary signals on emotional processing. Healthy volunteers were shown photographs of individuals with different pupil sizes with happy, angry, sad, frightened and neutral facial expressions. The volunteers were asked to perform visual analogue ratings of emotional facial expressions in three dimensions: the positivity/negativity, emotional intensity and attractiveness of the facial expression. Sad faces with smaller pupils produced more negativity and more emotional intensity that resulted in higher empathy scores. Interestingly, the degree to which participants were affected by the pupil size manipulation correlated with measures of emotional empathy. When the pupil responses of the participants were examined, it was found that there was coherence in the observed and observer's pupils; only in the context of sadness, (*i.e.* seeing a sad face with small pupils caused the participants' own pupils to constrict more). These observations showed an autonomic contagion in emotional processing, mirroring only in the context of perceived sadness, which is derived from individual differences in empathy for others [36].

Self-initiated movements, imagined movements, and action observation can attenuate mu rhythm recorded from electrodes over sensorimotor cortex [2] [37].

According to research reports, mu suppression is closely linked to mirror-neuron activity [13] [38]. The mu suppression can be a reliable indicator of sensorimotor involvement, supported by the mirror-neuron system, when participants perceive other people in painful situations [26].

The electroencephalographic mu suppression was measured in male and female participants to explore if there was any gender differences in the neural mechanisms involved in perception of the pain in others. Females should exhibit stronger sensorimotor resonance than males, as indicated by EEG mu suppression of empathy for pain. The gender differences in the degree of sensorimotor resonances may be related to the self-reported empathy of the participants [39].

6. Role of Mirror Neurons on Maternal Behavior

Maternal behavior is very important for perpetuating the human species. Specifically, fMRI brain activity of human mothers has been examined while they listen to infant cries, infant laugh and neutral noises to evaluate maternal caretaking behavior. Maternal response to infant cries is an indicator of how responsive she is to other infant cues and can be studied to detect maternal behavior [40]. Additionally, maternal response to infant cries may be used in the differentiation of nurturing and maltreating mothers. Swain *et al*. [41] recorded increased brain activity in the medial frontal cortex, basal ganglia and hippocampus of mothers with 2 - 4 week old babies.

When the infant rodents, monkeys, and humans are taken away from their mothers, they cry and the mothers express maternal behavior, such as orienting, searching, and retrieving [40] [42]. In most of the researches, fMRI has been used to explore the brain basis and the effects of human maternal behavior.

The effect of visual, auditory, tactile and vestibular stimulation on maternal brain were investigated and it was found that the altered corticolimbic responses of maternal brain to those impulses are related to mirror neurons in frontal, insular, superior temporoparietal cortex area, cingulate cortex and hippocampus of brain [43].

Removal of medial aspects of cerebral cortex, including most of the anterior and posterior cingulate cortex, has been shown to substantially alter maternal behavior in rats, hamsters and mice [44]-[47]. Motivation to care for pups appears to be present in mothers with cingulate-lesions but mothering behavior seems disjointed and disorganized. Although they try to retrieve separated pups, they often drop them so that pups are scattered around the cage rather than in the nest [45]-[47].

Lorberbaum *et al*. [48] evaluated the fMRI of mothers while they were listening to the recorded, infant cries and white noise as control sound. The mothers reported greater sadness and urges to help when they listened to the cries, and the fMRI data revealed statistically greater activity in the subgenual anterior cingulate, right mesial prefrontal cortex, and right orbitofrontal cortex than the white noise [48]. Maltreating mothers have less empathetic and aversive feelings toward a crying infant [49].

MacLean [44] reported that the thalamocingulate division is present only in mammals but not in lizard like reptiles, which, unlike mammals, do not cry and exhibit minimal parental care. In addition, large anterior cingulate lesions disrupt crying at separation in squirrel monkeys [50].

7. Conclusions

It is believed that mirror neuron system in human is the basic mechanism necessary for social cognition. It's also belived that mirror neurons are necessary understanding the process, intention, and emotion in any activity [8] [29].

In our daily life, we are affected by speech, gestures, and facial expressions of other people we watch on television or see personally, and start to think and behave like them. Sometimes, even without being aware of, we imitate their words or phrases.

We start to yawn next to someone who feels sleepy and yawns. Sometimes when we observe someone crying, we also start to cry without any reason even if we do not want to. During the time a mother feeds her child, while trying to open the baby's mouth, most of the time she opens her mouth unconsciously. Even without living the moment by ourselves, we have the ability to mimic the observed auditory and visual stimuli with the aid of mirror neurons. Although many researches have been made on that subject, there are still many unanswered questions related to mirror neurons such as whether it is possible to show mirror neurons histologically or the mechanism of activation of the neurons located in different areas of the brain. Which neurotransmitters play a role in the mirror neuron activity? Can we improve mirroring ability if we observe/listen more? Further research is needed to answer and explain all our questions.

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