# The Contribution of the Mirror Neuron System to Emotional Empathy

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## Introduction

The mirror neuron system (MNS) has been proposed as the neuronal substrate underlying a great variety of functions. Including imitation, language acquisition, intention understanding of others and empathy. The possible implication of the MNS in this functions has led to the speculation that this mirror system in people may form the basis for social behaviour.

In this bibliographical review, we focus our interest in the contribution of the MNS to social behaviour, through empathy. We will focus our research interest on emotional empathy.

**Emotional empathy: the ability to physically feel along with another person, as if their emotions were contagious.**

The first definition of mirror neuron (MN) defined them as motor neurons which discharged both during monkey's active movements and when the monkey observed the same hand movements made by the experimenter. Findings suggest that rather than being confined to a particular brain area, there might be a general mirroring mechanism that might constitute a particular way of processing information in the brain.

**Mirror neuron: a neuron that fires both when a subject performs an action and when the subject observes the same action performed by another, showing a degree of action specificity.**

We addressed the following questions:

- What is the contribution of the MNS to emotional empathy? Is the MNS underlying emotional empathy?
- Do disruptions of the MNS affect emotional empathy?

To do so, we analyzed:

- Evidence of MNs in the monkey and human brain and in brain areas relevant for emotional empathy.
- Theories linking the MNS and emotional empathy.
- Correlations between disruption of MN activity and emotional empathy.

## Materials and methods

Search for scientific literature on PubMed database. Papers and reviews were selected upon relevance, journal impact factor and date of publication. Key words used: "mirror neurons", "mirror neuron system", "emotion", "empathy", "autism" and "schizophrenia". Over 50 papers and reviews, published in between 2003 and 2015, where selected and data from 23 of those was used in this review.

## Results

MN activity cannot be unambiguously detected through neuroimaging techniques. In that sense, single neuron recordings remain the reference technique for obtaining direct evidence of MN activity. MNs were firstly described in the rostral division of the ventral premotor cortex, F5, in the macaque brain. Since then, numerous studies have aimed to asses MN populations in different brain areas using single neuron recording in the macaque brain. They have been reported in the inferior parietal lobule, including lateral and ventral intraparietal areas, and in the dorsal premotor and primary motor cortex.

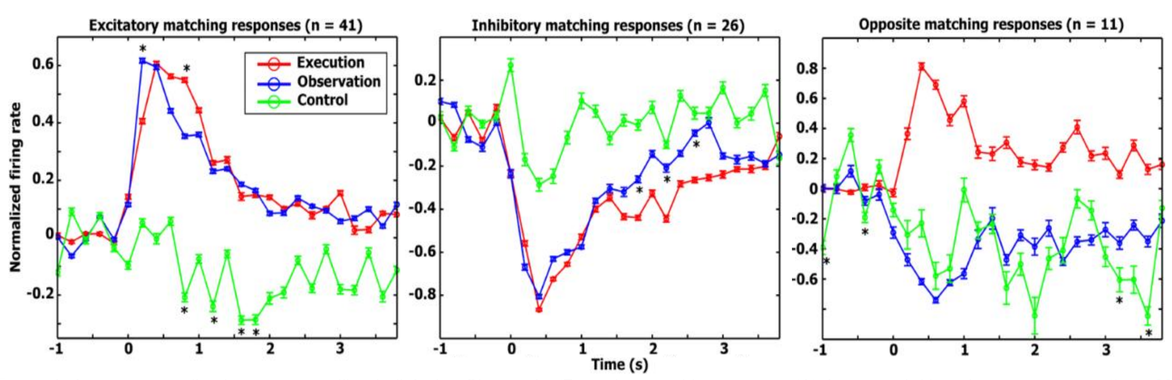


Figure 1. Average normalized response profile of all Action Observation/Execution matching neurons. (A) Average of 41 excitatory responses (from 33 different neurons) during action execution and action observation. (B) Average of 26 inhibitory response (from 21 different neurons). (C) Average of 11 response profiles (from 11 different neurons) exhibiting excitation during action-execution and inhibition during action-observation. Modified from Mukamel et al., 2010.

In humans, to this date only one study have recorded single neuron responses during execution and observation of actions. Including facial emotional expressions. Extracellular activity was recorded from neurons in the medial frontal and temporal cortices. A significant proportion of neurons in the supplementary motor area, and hippocampus and surrounding areas, responded both to observation and execution of actions tested. A subset of these neurons demonstrated excitation during action-execution and inhibition during action-observation (**Figure 1**). To our best knowledge, this is the first study to asses MN activity in humans through single neuron recordings. These data demonstrates mirroring neuronal activation during action-execution and action-observation in the human medial frontal cortex and medial temporal cortex, where mirroring responses at single neuron level had not been previously reported.

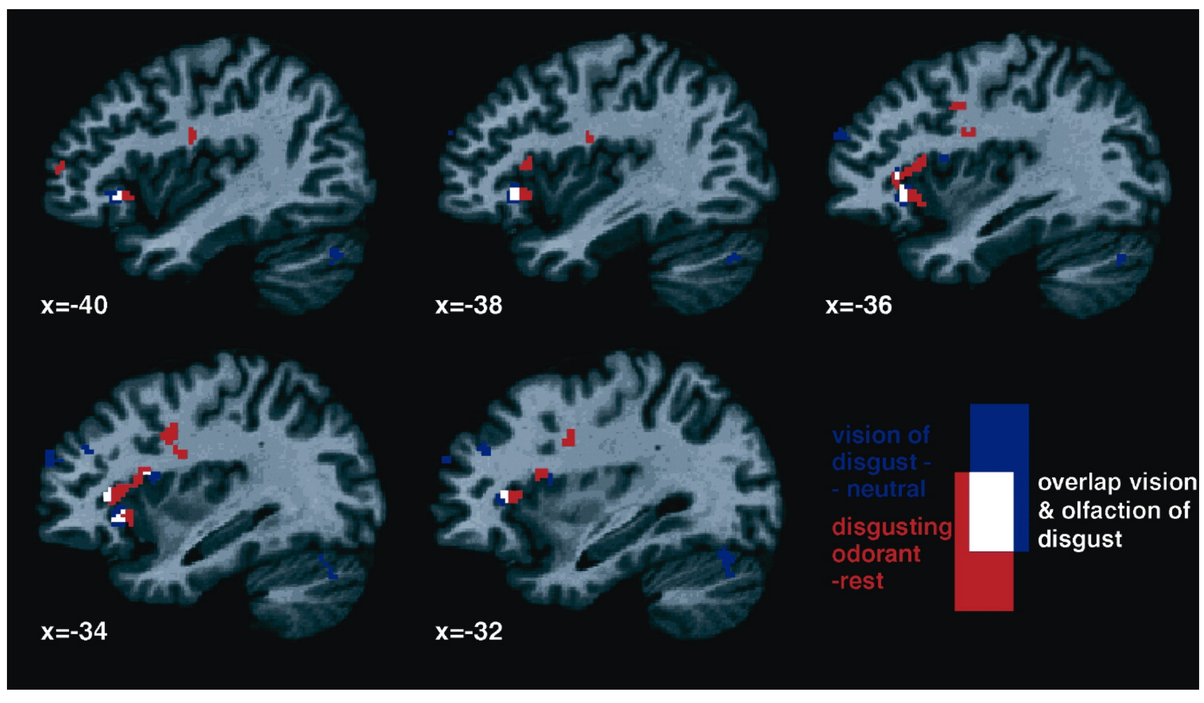


Figure 2. Illustration of the overlap (white) between the brain activation during the observation (blue) and the feeling (red) of disgust. The olfactory and visual analysis were performed separately as random-effect analysis. The results are superimposed on parasagittal slices of a standard MNI brain. Modified from Wicker et al., 2003.

Neuroimaging studies in humans, particularly using fMRI, confirm a broad overlap between brain areas that activate during action observation and areas where MN have been reported in single-unit recordings in monkeys. BOLD signal changes during action observation seem to be consistent with the presence of a MNS in humans, but they cannot yet provide conclusive evidence.

In order to asses the contribution of MN activity to emotional empathy, we addressed the question of which brain areas are involved and relevant in this process. There is not a straight-forward answer for this question and it shall be seen at an emotion-specific level. In that sense, we will use the example of disgust, were prolific results were achieved by Wicker et al., 2003. This shall be seen as an example of an experimental approach to study brain areas with MN activity involved in emotional empathy.

Disgust is a crucial emotion to avoid food poisoning, which can be a substantial threat in a natural environment. When an observer sees a conspecific expressing disgust after tasting some food, the individual automatically infers that the food is bad and should not be eaten. The authors hypothesis predicts that brain areas involved in experiencing disgust also become active during observation of disgust in others. Thus, leading to the observer to feel disgust as well. To test this, Wicker's group performed fMRI while human subjects inhaled odorants that produced a strong feeling of disgust and then while the same participants observed a video of the emotional facial expression of disgust in another person. Their results showed that observation of facial expressions and feeling the disgust produced by the odorant, activated the same brain site in the anterior insula (and to a lesser extent in the anterior cingulate cortex) (**Figure 2**).

Furthermore, the insula may be a critical relay in MNS circuits that contribute to emotional empathy. The superior temporal and inferior frontal cortices are connected to the limbic system via the insula (Carr et al., 2003). In **Figure 3** we can see a schematic diagram of this possible neural circuit where the MNS involved in intention understanding and emotional empathy.

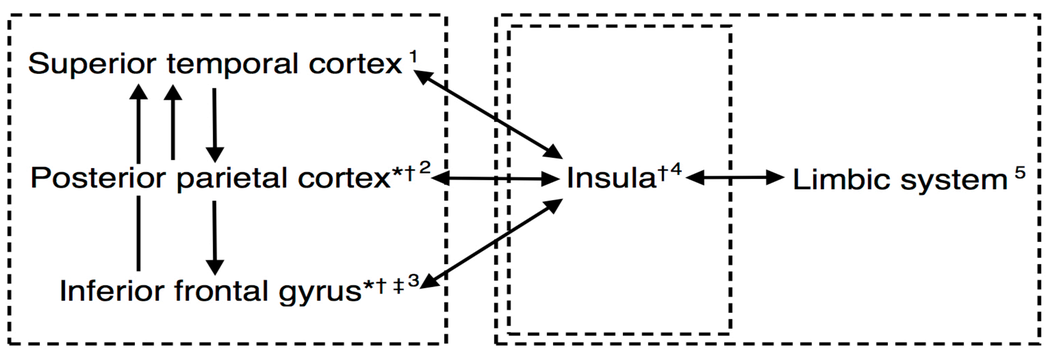


Figure 3. Schematic diagram of a possible neural circuit involved in the contribution of the MNS to emotional empathy, as described by Carr et al., 2003. Arrows represent neural projections. Box on the left: frontoparietal networks connected to the superior temporal cortex. (1) Superior temporal cortex: encodes early visual description. (2) Posterior parietal cortex: encoding of kinaesthetic aspects of movement. (3) Inferior frontal gyrus: codes goal of action recognition. Boxes on the right: areas relevant to emotional empathy in terms experiencing emotion.
* Evidence of MN activity through single-unit recordings in monkey.
† Evidence of MN activity through neuroimaging in humans.
‡ Evidence showing no MN activity in patients with autism.

Several studies have linked autism spectrum disorders with MN deficits. Autism is characterized by complex behavioral phenotypes, that include deficits in social and cognitive functions. Some authors have postulated that MNs appear to be performing precisely the same functions that are disrupted in autism.

In Dapretto et al., 2006, high-functioning children with autism and matched controls underwent fMRI while observing and imitating emotional expressions. Interestingly, both groups performed the task equally well. But children with autism showed no MN activity in the inferior frontal gyrus. Notably, this activity was inversely correlated to symptom severity in terms of social deficits (**Figure 4**). This findings suggest that the neural strategies adopted by typically developing children and children with autism vary significantly. Typically developing children can rely on MN networks, interfacing with the limbic system via the insula, experiencing emotional empathy. In contrast, children with autism seem not to have this mirroring system engaged in this task. Instead, they show an increased visual and motor attention.

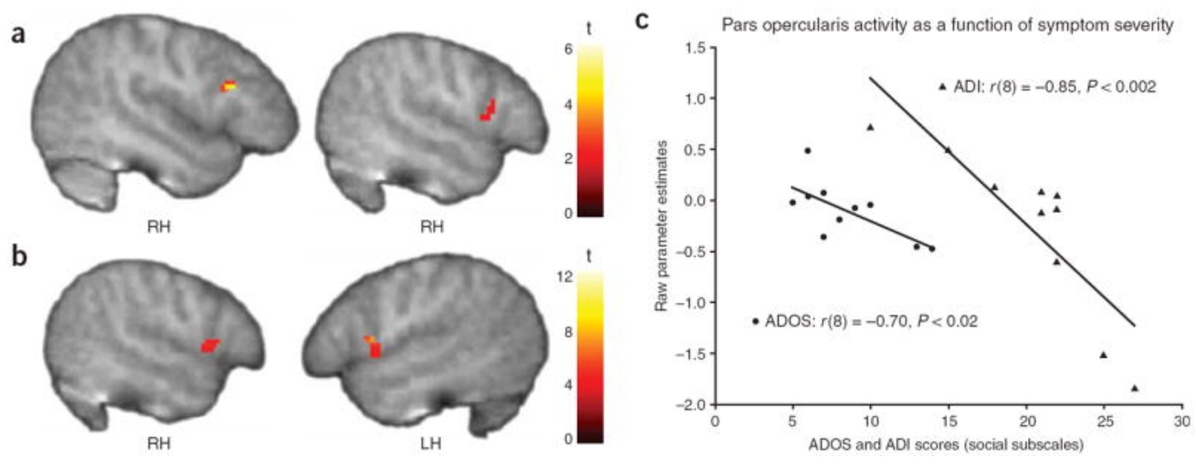


Figure 4. Mirror neuron system activity and symptom severity. (a–c) Negative correlations were found in the ASD group between activity in the pars opercularis of the inferior frontal gyrus and scores on the social subscale of both ADOS-G (a,c) and ADI-R (b,c). T > 1.83, P < 0.05, corrected for multiple comparisons at the cluster level. From Dapretto et al., 2005.

Finally, studies have explored a possible link between MN dysfunction and schizophrenia. Multifaceted social deficits are associated with schizophrenia, including empathy and emotional processing. Studies show evidence of poorer MN activity during facial emotion expression observation. Moreover, altered self-reported empathy scores in facial emotion processing are described in this patients.

## Conclusions

- Single-neuron recordings studies have proven the existence of MNs both in monkey and in human. Nonetheless, many brain areas remained unexplored through this techniques and percentages of MNs remain unclear for many studied areas.
- Neuroimaging in humans studies have provided with a substancial body of evidence supporting the existence of a MNS in humans, in agreement with finding in single-neuron recordings.
- In autism, reduced MN activity has been correlated with symptom severity and different neural circuits have been described in processing observed facial emotion expressions compared to normally developing children.
- Studies in patients with schizophrenia have described a poorer MN activity too, as well as altered self-reported empathy scores in facial emotion processing.

While the contribution of the MNS to emotional empathy remains unclear, there is a strong body of evidence that suggests that this neural system in fact exists in humans and may be underlying a variety of functions, including emotional empathy. The MNS may in part contribute to emotional empathy and social behaviour, alongside several other neural and cognitive processes, that shall be seen as functionally complementary. Future studies will be needed to fully assess the contribution of the MNS to emotional empathy.

## References

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