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How we empathize with others: A neurobiological perspective

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Summary

Empathy allows us to internally simulate the affective and cognitive mental states of others. Neurobiological studies suggest that empathy is a complex phenomenon, which can be described using a model that includes 2 modes of processing: bottom-up and top-down. Bottom-up neural processing is achieved via the mirroring representation systems that play a key role in the direct sharing of the emotional states of others. Top-down processing, known as *cognitive perspective-taking* or *theory of mind*, where the feelings of others are fully imagined and understood, is based on control and inhibition mechanisms. Available evidence indicates that empathic brain responses are likely to be influenced by several different modulating factors.

key words: **empathy • mirror neurons • perspective taking • theory of mind • anterior cingulate cortex • anterior insula**

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Background

Empathy (Gr. *empatheia*-passion) has been the subject of much study in social and developmental psychology, sociology and philosophy, and it has been defined in many different ways. The perception of the emotional state of others can result in emotional empathy, that is, elicitation of corresponding emotions in the observer, and moreover, sharing an emotional state with others [1,2]. However, empathy allows us to internally simulate not only the affective states of others, but also their cognitive mental states. Thus, empathy can also refer to our ability to take the cognitive perspective of other people, which helps us to understand their experiences, intentions, and needs [3,4].

In recent years, work in social neuroscience has begun to shed light on the neural underpinnings of empathy. The aim of this article is to review the findings of recent studies investigating how we empathize with others from a neurobiological perspective. The nature of individual differences in empathy is an important issue that could be considerate from both a scientific and a therapeutic point of view. Therefore, several factors that modulate the level of empathy, measured by changes in the activation of relevant brain areas, are discussed.

The Role of Bottom-Up Processing of Affective Sharing – Social Mirroring

For many years, researchers have undertaken efforts to explain the automatic mode of our perception of the emotional states of others and understanding of their feelings, behaviors, intentions, and needs. Recent studies have suggested that empathy may be based on so-called *mirroring systems* or the *mirror neuron system* (MNS). The mirror neurons found in the central promoter (area F5) and parietal (area PF) cortex were originally discovered in a monkey brain [5–7]. These cells fire during goal-directed actions (holding, grasping, or manipulating objects), and when a monkey observes the same actions performed by others, either monkeys or humans.

There are 2 classes of visuomotor neurons in monkey area F5: *mirror neurons*, which respond when the monkey sees an object-directed action, and *canonical neurons*, which respond to the presentation of an object. The object significance for a monkey has no obvious influence on the mirror-neuron response. They fire with the same intensity responding to grasping a piece of food or a geometric solid [6]. It has been argued that the functional role of the MNS understands the behavior of others based on direct mapping of a motor or somatosensory representation of the observed action in the observer brain [8,9]. Data from neuroimaging and electrophysiology studies in humans support this notion and indicate that the MNS involves the inferior parietal lobule (IPL) and the inferior frontal gyrus (IFG) [10] (Figure 1). These 2 areas are anatomically connected and form an integrated frontoparietal MNS [11]. The MNS operates according to the principle of "a mirror" – if one raises one's right hand, we observe and understand this action by activating our own neural representation of this action even when we do not perform the action ourselves but observe others doing it [6]. This mirroring process is automatic [12].

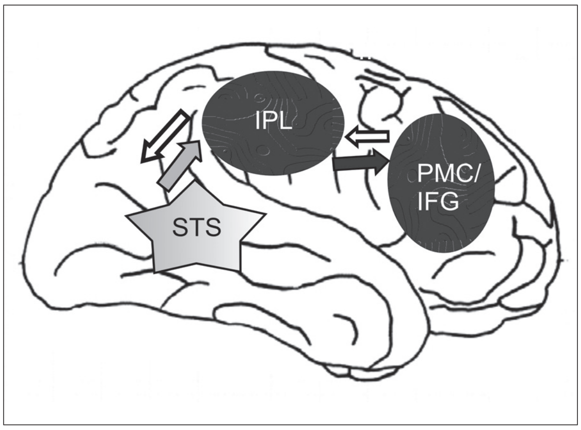

Figure 1. Neuronal basis of imitation (after [11], modified). The Figure shows the frontoparietal mirror neuron system (MNS) (black ovals) and visual input (grey star) in the human brain. The anterior area of the MNS involves the posterior inferior frontal gyrus (IFG) and the ventral premotor cortex (PMC), and the rostral area involves the inferior parietal lobule (IPL). The grey arrow indicates input to the MNS from the STS. The black arrow shows the information flow from the IPL to the PMC/IFG. The white arrows show the information flow from PMC/IFG to the IPL and to the STS (based on [11]).

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Mirror neurons are activated when we observe or imagine some movement [13] and when we imitate others [11,14]. A schematic representation of the neural circuitry for imitation based on the MNS is shown in Figure 1.

For example, functional MRI studies on the imitation of simple movements or complex guitar fingering have shown that frontoparietal MNS is active in both cases. The MNS exhibits the highest activity during complex tasks [11,15].

Developmental behavioral data show that imitative behavior is crucial for developing social cognitive skills [11]. The behavioral links between imitation and social cognition suggest a key role for the MNS not only in understanding the intentions of others but also in sharing the emotions of others [11]. An fMRI study on the possible role of the MNS in emotional processes has shown that when people observe or imitate facial expressions of different emotions, structures connected with the representation of emotional states and facial movements are activated: the superior temporal sulcus (STS), the anterior insula (AI), the amygdala, and the premotor cortex (PMC) [16]. These data indicate that a mechanism using the same affective neurons is connected both with generating our own emotional states and with the MNS emotional operation.

Influenced by the concept of the MNS involved in understanding of motor behavior and imitation, Preston and de Waal [4] proposed a neuroscientific model of empathy. Their perception-action model suggests that the observation or imagination of another person in a particular emotional state automatically activates a representation of that state in the observer, with its associated autonomic and somatic responses [4]. Based on this inner representation, we can recognize the emotions of others and express them with gestures or facial expressions. The shared affective neural

Figure 2. Key brain structures involved in empathy connected with the 2 modes of processing information: bottom-up (light grey) and top-down (dark grey) interoception. MPFC – medial prefrontal cortex; TPJ – temporo-parietal junction; STS – superior temporal sulcus; TP – temporal pole; ACC – anterior cingulate cortex; AI – anterior insula; SII – somatosensory cortex (after [39], modified).

activation between self and others explains how we can feel the emotions of others [17].

Decety and Lamm [18] proposed a model in which bottom-up information processes (direct matching between perception and action) are fundamentally intertwined in the generation of empathy [19]. In these processes, the activated sensory transformation system in the temporal cortex (STS) "switches on" the MNS in the limbic system, and this neural information is transmitted to higher cortex structures responsible for executive functions. Imaging studies using fMRI have revealed that both the observation of pictures showing disgusted faces and the actual smelling of disgusting odors elicit similar brain activity: in the anterior cingulate cortex (ACC) and the AI, structures associated with empathic response in the domain of smell [20]. The assumed presence of affective mirroring in empathy is derived from studies on the empathy of pain [21–29]. In most fMRI studies on the observation or imagining of the pain of others in adults and children, activity has been predominately found in ACC and AI [24,28–36]. It has been suggested that these regions play a crucial role in representing one's own subjective feeling states and affective processing of pain [37] in nonempathy conditions of "first hand" experience of the emotion, that is, when we experience pain ourselves [38]. This supports the notion that empathizing with others activates the neural network underlying this specific emotion in the empathizer [39]. In other words, when we want to understand how others feel when in pain, we activate the same neural networks, which are crucial for our own feelings of pain.

A question remains of how much the empathic reaction of the empathizer is isomorphic to the observed affective process of others. Most research on the empathy of pain conducted using the fMRI indicates that emphatic reactions are connected with the affective component of pain, namely with activation of the ACC and the AI, rather than with the sensory component of pain associated with activation of somatosensory cortex [24,25]. However, other studies using transcranial magnetic stimulation (TMS) [22], magnetoencephalography (MEG) [40] or somatosensory-evoked potentials (SEPs) [41], revealed that while empathizing with the pain of others, somatosensory cortices (SI) and (SII) can also be activated in areas related to pain signal transmission pathways, which indicates "direct mirroring of feeling pain." These findings suggest that both sensory (SI and SII) and affective components (ACC and AI) of pain are likely to be involved in the process of empathizing.

The Role of Top-Down Processing of Cognitive Perspective-Taking

Witnessing others undergoing various emotions is a frequent occurrence. Taking MNS for granted, it could be assumed that we constantly share emotions of others in an unconscious way. In this situation, empathy would resemble *mimicry* – that is, a tendency to automatically synchronize affective expressions, vocalizations, postures, and movements with those of another person [42,43]. Automatic sharing the emotions of others might imply continuously being in some form of emotional chaos owing to an inability to distinguish between our own emotion and that of others, yet such a situation does not occur. When empathizing with the emotions or sensations of another person (affective empathy), cognitive perspective-taking (cognitive empathy) takes place which supports our ability to understand the intentions, desires, and beliefs of others [39]. The first step of cognitive perspective-taking is to distinguish between ourselves and others. In the next step, we imagine how another person feels and understand his or her intentions, desires, and beliefs [44]. This cognitive inference of the mental state of the other person is known as *mentalizing* [45] or having a theory of mind (ToM) [46,47]

It has been proposed that top-down processing in which mainly prefrontal cortex areas are engaged [48] could be responsible for cognitive perspective-taking which might "protect" from automatic execution of mimicrylike processing. At the moment, when we are trying to understand what another person feels, the autonomic and somatic neuronal circuits responsible for direct sharing his/her emotional states might be inhibited. Studies using fMRI have shown that when participants were asked to consider the emotional state of a person shown in a cartoon or described in a story, the following brain regions were activated: the medial prefrontal cortex (MPFC), the temporo-parietal junction (TPJ), the STS, and the temporal pole (TP) [39,49,50]. The brain regions that participate in cognitive perspective-taking are shown in Figure 2.

Medial prefrontal cortex around BA 9 has been implicated in both sharing empathy and theory of mind [50]. Thus, it is likely that neural networks involved in mentalizing or ToM constitute the extended system supporting empathy. In addition, there is evidence that the region around paracingulate sulcus in MPFC contains spindle cells, a class of large projection neurons found only in great apes and humans, which are thought to be involved in coordinating neural activity relating to emotion and cognition [3,51]. In this area, neuronal circuits involved in sharing emotional states (affective empathy) could intertwine with those taking part in perspective-taking (cognitive empathy).

In a study by Ruby and Decety [52], the participants were presented with short written sentences depicting real-life situations likely to induce social emotions, and were asked to imagine how their mothers would feel if they were in such situations. It was shown that the MPFC and the ventromedial prefrontal cortex (VMPFC) as well as the right IPL were activated in these individuals.

Functional brain imaging studies in individuals with autism have found evidence of abnormal brain activation in VMPFC, ACC, TPJ, and TP during tasks aimed at eliciting social cognitive responses [53–55]. Interestingly, studies of people with autism spectrum disorders (ASD) indicate that VMPFC, anterior cingulate gyri, and TPJ exhibit reduced fractional anisotropy (FA) values, which is an indicator of the diameter and density of fibers, myelination, and macrostructural features of white matter fibers [56,57]. All those structures are implicated in social cognitive processes, such as ToM. Moreover, these individuals have a dysfunction of the MNS associated with a behavioral deficiency in recognizing and sharing emotions with others [11]. This impairment may reflect a dysfunction of both bottom-up and top-down processing in people with ASD.

There is also clinical evidence that frontal damage (the frontopolar cortex) can result in impaired perspective-taking ability [58]. In such cases, top-down regulation through executive functions is no longer active. However, the MNS could still be active, which may lead to mimicry or the chameleon effect [2,42]. On the other hand, the level of anxiety and discomfort of such people could be higher, which may lead to personal distress. Similar effects are also observed in small children in whom prefrontal cortex is immature [19,59,60]. For example, babies start crying when they hear other babies crying. An atypical pattern of activation in empathy-related brain areas is also observed in some mental disorders.

It has been reported that adolescents with childhood-onset aggressive conduct disorder (CD), show no activation in neural regions that contribute to self-regulation and metacognition (including moral reasoning), such as the MPFC, the TPJ, and the lateral orbitofrontal cortex (OFC), and exhibit activation in insula and precentral gyrus when watching situations in which pain was intentionally inflicted [61]. It has been proposed that adolescents with CD may be more likely to respond aggressively because their empathic mimicry might produce high levels of distress. Their deficiencies in the reactions to painful situations also suggest a lack of cognitive perspective-taking. These findings indicate that CD adolescents might be dysfunctional in top-down processing of empathy-inducing information.

Factors Modulating Empathy

Most fMRI studies have shown that the empathic brain is activated when participants watch video-films featuring situations in which pain is experienced [62], observe faces expressing pain [27], or observe cartoon images of painful situations, for example, trapping one's finger in a door or crushing one's toe under a heavy object [28]. These empathic brain responses vary depending on modulating factors such as the intensity of the stimulation or the displayed emotion [17]. Stronger activations in the AI and the ACC were recorded in situations where participants watched pictures showing the faces of patients having acute rather than chronic pain [29], or when they observed a needle deeply penetrating body parts (rated as high pain intensity), rather than just scratching the surface of the skin (rated as low pain intensity) [22]. The greater the intensity of the stimulation of pain or its facial expression, the higher the level of empathic brain activation observed [39]. Another factor modulating the empathy level is the relationship between the subject observed and the person empathizing. It was found that when the person empathizing was related to the individual in pain or when their relationship was of an emotional nature, the level of activity in the ACC and in the AI was greater [33,63]. Nevertheless, it should be noted that activation of the aforementioned areas also takes place when we empathize with a stranger or a person to whom we are not related [62,64].

The human response to pain of others can also be modulated by situation and its context. Lamm and associates [32] showed participants video clips featuring the faces of patients with neurologic disease (Tinnitus aurium) as they – within the framework of therapy – listened to unpleasant sounds. The brain empathic response was much smaller when the participants were convinced that the pain was inflicted with a therapeutic purpose [32]. In another fMRI experiment, participants were shown pictures of a hand or hands being pierced with a needle. Next, to divert their attention from the painful situation, they were asked to count the number of hands. The activation rate of particular brain areas (ACC, AI) was significantly lower in the second case, showing that attention processes affect the level of empathy, with distraction reducing it [31].

Interestingly, the characteristics of the person empathizing, and their experience or profession also affect the process of empathizing. The level of pain empathy was found to be lower in an acupuncturist than in people from a control group, which indicates diminished pain sensitivity in those involved in pain therapy [30].

Another significant factor modulating empathy is sex – both of the person being empathized with and of the person empathizing. A higher level of activity was noted in amygdala, the ACC, and in the somatosensory cortex when participants observed pain expressed on the faces of men rather than on those of women [65]. Strong activation was observed in the amygdala of both men and women. It could be assumed that the observation of an expression of pain on a man's face is a distinctive signal of a threat that can lead to the conditioning of fear, for which amygdala is mainly responsible [27]. Owing to the stereotype of a woman's role in inspiring harmony or creating a loving home, women are

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perceived as being more empathic than men. The results of several studies seem to confirm this assumption. For example, studies on the reactive cry of babies (baby starts to cry because other babies cry) as a primitive manifestation of empathy show that female infants behave in this way more often than do males [39].

Reactions of men and women can vary depending on the characteristics of the person they are empathizing with. Both men and women have been found to empathize with the pain of individuals whom they watched playing fair in a monetary investment game before the fMRI study. Receiving mild electric shocks by those individuals evoked activations in brain areas associated with pain and empathy in both sexes. However, when the shock was delivered to individuals who played unfair, men's brains showed no increased activity in the empathy-related pain areas. Furthermore, high levels of activity have been observed in the brain regions associated with reward, namely the ventral tegmental area (VTA) and the nucleus accumbens (NA). Interestingly, the magnitude of this effect correlated positively with the intensity of the desire for revenge, admitted in a questionnaire filled after the experiment [25]. This suggests that empathic reactions in men are shaped by perceived fairness of others, and they could even derive a satisfaction from seeing the unfair individual being punished. In contrast to this, a woman's brain reaction to viewing the unfair person being shocked was similar (though slightly weaker) to that displayed toward the fair player.

Recordings of EEG [66] and MEG [40], and recently, the use of voxel-based morphometry (VBM) have demonstrated neuroanatomic and neurophysiological differences between the sexes in the MNS [67]. Voxel-based morphometry revealed that pars opercularis of prefrontal cortex and parietal lobe, that is, the areas in which mirror neurons are located, contain more grey matter in women than in men. Moreover, changes in the activity of these neurons measured by MEG in the *mu* frequency band (~20 Hz) were greater for women than they were for men when observing situations connected with pain [68], which may indicate that in terms of neuroanatomic features and neurophysiological mechanisms, women are adapted to strongly empathize with others. It may be speculated that this adaptation is connected with their role of being a mother and allows them to quickly recognize and empathize with the emotions of children, and consequently, to react in a more-rapid and precise manner, especially in threatening situations. This ability is colloquially referred to as *women's insight.* Mirror neuron activity in women may be of such magnitude that its inhibition by the prefrontal area is insufficient, leading to more-effective bottom-up processing than in men.

Conclusions

Neurobiological studies suggest that there are at least 2 modes of processing information in empathy: bottom-up and top-down. The mirror neuron system is probably engaged in the former, automatic processing mode. Neuroimaging studies indicate that the same areas of the brain are activated when people experience their own emotions and when they observe such emotions in others. Sharing an emotional state with others is, thus, an important aspect of empathizing. The ACC, the AI, and the somatosensory cortex

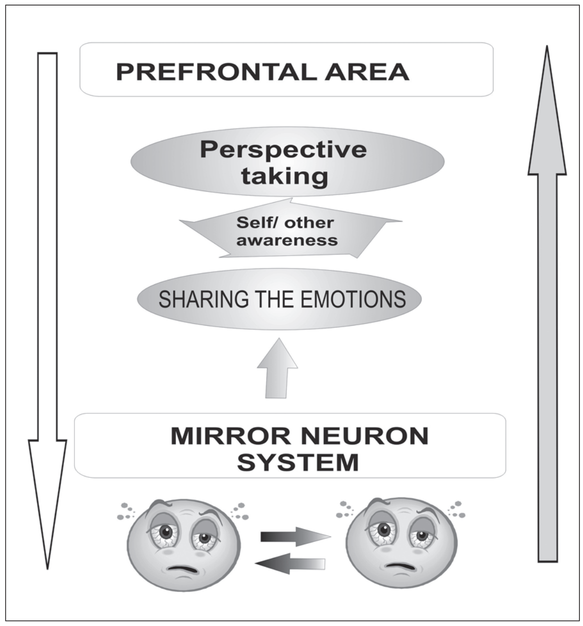

Figure 3. Two modes of processing information engaged in empathy: bottom-up (grey arrow) and top-down (white arrow) (after [18], modified).

take part in this process. Understanding of others' feelings by taking their perspective is another vital factor in empathizing. Therefore, when we try to understand what others feel, autonomic and somatic neural pathways responsible for empathizing with the emotional state of others' can be inhibited by top-down circuits involving mainly prefrontal areas of the brain (Figure 3). Various modulating factors affect the level of empathic response. It increases when the pain observed is greater, occurs suddenly, or when the person we empathize with is close or similar to us, and when the pain is inflicted for a nontherapeutic purpose. In addition, the sex of the observer is also important; women usually have a greater level of empathy than men, regardless of whether they like or dislike the person they empathize with. The empathic responses in men depend on the perceived fairness of others.

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