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Mirror Neurons and Social Implications for the Classroom

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Introduction

Nearly three decades ago in a neuroscience laboratory in Parma, Italy, a monkey, some peanuts, and a happy accident stunned the scientific community. During an experiment, every time a monkey grasped a peanut, as expected the cells in a brain region (F5) being monitored would fire. However, after the experiment was over, it came as quite a surprise to the researchers when the very same brain cells that fired when the monkey made an action also fired if the monkey watched someone else move peanuts toward their own mouth, even if the monkey had not moved at all (Blakeslee, 2006). These cells became known as mirror neurons (di Pellegrino et al., 1992).

Since the discovery of visuomotor mirror neurons, auditory mirror neurons have also been discovered, where the sounds of actions activate our own motor representations of those actions (Aziz-Zadeh et al., 2004; Kohler et al., 2002). Although mirror neurons were originally discovered in the macaque monkey (di Pellegrino et al. 1992), a large body of evidence has accumulated in support of their existence in humans (for a review, see Fogassi & Rizzolatti, 2013), although there is some controversy around their role (for a review, see Hickok, 2009). The putative human mirror neuron system (MNS) is thought to consist of a frontal portion, primarily in the ventral premotor cortex (PMv) and the pars opercularis of the inferior frontal gyrus (IFGop), and a parietal portion, primarily in the inferior parietal lobule (IPL) (see figure 16.1). The MNS brain regions are activated both when performing actions and when observing or listening to others performing similar actions (Rizzolatti & Craighero, 2004). In other words, this system uses one's own neural motor representations to process and help understand sensory representations related to other people's actions. Through simulation, the MNS provides a "mirror" between others' actions and self-actions, enabling individuals to experience them firsthand. If you have ever had the experience of unknowingly crossing your legs when

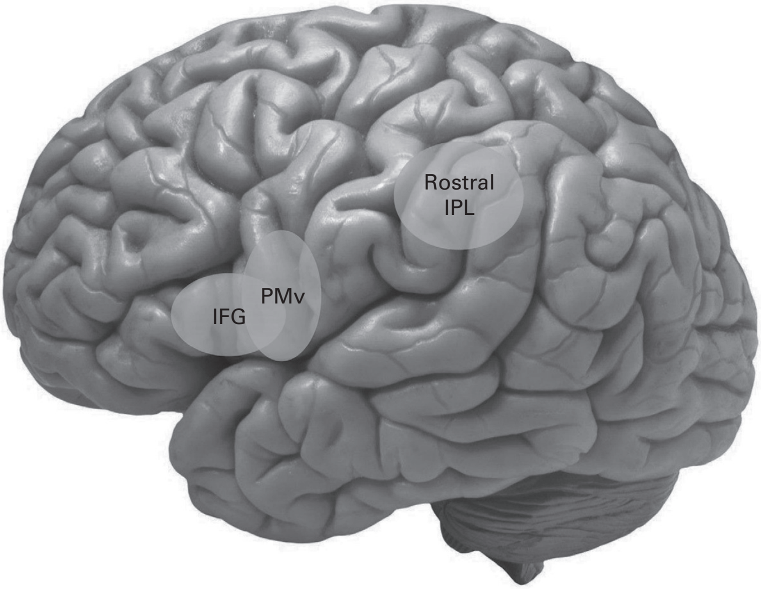

Figure 16.1
Areas of the human mirror neuron system. Lateral view of brain with frontal (PMv and IFG) and parietal (rostral IPL) mirror neuron regions. IFG, inferior frontal gyrus; IPL, inferior parietal lobule; PMv, ventral premotor cortex.

sitting across from someone else crossing their legs, then you have experienced your MNS at work!

The discovery of mirror neurons has captivated scientists and educators alike. The existence of mirror neurons revived a long-standing debate in psychology and neuroscience about how we process the actions and intentions of others. To some, mirror neurons provide a neurological support for the theory of embodied cognition (Rizzolatti et al., 1996).

Embodied cognition is a theory that posits that higher cognitive processing such as intention understanding, language, and cognition, may rely, in part, on fundamental brain regions involved in action production and sensory processing. This view is the opposite of cognitive or symbolic theories, and suggests that semantic knowledge, and much of cognition, is carried by sensorimotor representations (for review Caramazza et al., 2014). Understanding this system and how it interacts with other neural regions as well as the rest of the body and behavior may be one informative tool for devising better ways to improve learning and classroom environments. This chapter will explore how MNS regions, in collaboration with other neural networks, may contribute to larger motor and social-emotional learning processes. The mechanisms and functions of the MNS provide insight for the classroom setting in the context of (1) imitation learning, (2) empathy, (3) neurobiological evidence that learning is inherently embodied, and (4) evidence that learning requires involvement of emotional and social neural networks.

Imitation Learning: The Fallacy of “Do as I Say Not as I Do”

Imitation is critical for developing motor, communication, and social skills (Pfeifer et al., 2008). There are two main forms of imitative behaviors: imitative learning and social mirroring (or “chameleon effect”; Iacoboni, 2005). Early findings in newborns suggest that imitation is an innate ability (Meltzoff & Moore, 1977), and more recent work suggests that the strength of imitation ability is heavily influenced by early sensorimotor learning that occurs in an infant’s cultural and social environment (for review, see Ray & Heyes, 2011). The range in type and number of imitated behaviors, as well as their accuracy, increases with greater exposure to those behaviors (e.g., Jones, 2007). Therefore, in development children can learn and practice how certain actions are executed by imitating them (e.g., Brass & Heyes, 2005).

Imitation is both a motor and a social behavior; in fact, it is important for numerous aspects of social development including pretend play (Nadel, 2002), reading facial and body gestures (Hurley & Chater, 2005), theory of mind (Goldman, 2005; Meltzoff, 2007), moral development (Forman et al., 2004), mirror self-recognition (Nielsen & Dissanayake, 2004), and joint attention (Rogers et al., 2003). Further evidence of this association can be seen in autism spectrum disorder, where imitation deficits occur in relationship with general social cognition deficits (Iacoboni & Dapretto, 2006). Imitation also influences interpersonal relationships in adulthood; individuals frequently unconsciously imitate the gestures and facial expressions of others (Chartrand & van Baaren, 2009), especially to adapt to demands of a social situation (e.g., Iacoboni, 2009). This social mirroring creates rapport and a shared experience between social partners (Chartrand & van Baaren, 2009).

As previously reviewed, the MNS may be involved in understanding other people’s actions and intentions through embodied simulation (e.g., Fabbri-Destro & Rizzolatti, 2008). This system is involved in two necessary parts of imitation: action observation and action execution. Lesions in the IPL (an MNS region) can result in a deficit in imitation (Wheaton & Hallett, 2007), and lesions to the left IFG have resulted in impaired imitation of finger movements (Goldenberg & Karnath, 2006).

Another way of studying the neural correlates involved in imitation is through neuroimaging paradigms. An imitative music learning study of non-musicians showed that the MNS, along with motor preparation areas and the dorsolateral prefrontal cortex, is active when learning to play guitar chords through action observation (Buccino et al., 2004). In a large meta-analysis of functional magnetic resonance imaging imitation paradigms (Caspers et al., 2010), imitation tasks were consistently related to neural activation in a network of the IFGop, premotor, inferior parietal, intraparietal, primary somatosensory, and temporo-occipital areas. This network was active consistently regardless of what type of effector (hand, face, fingers, etc.) was being imitated, suggesting a general action imitation network.

These findings highlight two key points: (1) areas of the MNS (IFGop, PMv, IPL) are consistently active across imitation tasks, and (2) additional areas outside the MNS are involved in imitation and have simulation or mirrorlike properties, including the dorsal premotor cortex, supplementary motor area, posterior medial temporal gyrus, and middle temporal visual area (Caspers et al., 2010). Others have also shown support for a system that includes and extends the areas of the classic MNS in observation and imitation of actions (Iacoboni, 2009).

Children tend to imitate the goal of an action earlier in development rather than imitate the exact motoric and kinematic aspects of an action (Bekkering et al., 2000). Imitation may involve two processes: emulation and mimicry. An individual who emulates an action needs an understanding of the end goal or meaning of an action, whereas mimicry describes reproduction of low-level kinematic features and motoric aspects of any action, even if it is meaningless and does not have a goal (Hamilton, 2008). Emulation is carried out by coding goals of actions (in the IFGop), whereas mimicry is carried out by copying and coding of higher-order visual descriptions of actions (in the IPL and superior temporal sulcus) (Iacoboni, 2005).

Empathy

Empathy is a multifaceted construct defined by the ability to understand and experience the feelings of others (Dvash & Shamay-Tsoory, 2014). This capacity serves the evolutionary purposes of responding to social signals for reproduction, survival, parental care, and group cooperation (Preston & de Waal, 2002). Empathy is also a vital piece of human social interaction, necessary for formation and maintenance of interpersonal relationships, prediction of social expectations, and flexible responses to complex social scenarios (Thompson et al., 2016). Experiencing empathy can result in responses of sympathy, compassion, and prosocial action (Singer & Klimecki, 2014). Empathy allows us to understand others' experiences on an affective, cognitive, and sensory level.

Empathy as a construct can be delineated into dissociable dimensions of cognitive and emotional (sometimes called affective) components. Cognitive empathy refers to the ability to imagine and understand another person's thoughts, intentions, and feelings through an automatic (Frith & Frith, 2006) or intentional (Hein & Singer, 2008) process. Emotional empathy refers to the capacity for matching and sharing emotional responses to another individuals' emotional experiences (Davis, 1994). Although the mechanisms and functions of these dimensions do not completely overlap, they do interact in dynamic ways in social and emotional experiences (Zaki & Ochsner, 2012). Dysfunction of empathy and the MNS have been associated with various mental and developmental illnesses such as autism spectrum disorder, alexithymia, schizophrenia, and psychopathy (for review, see Jeon & Lee, 2018).

The MNS is likely to be only one of many neural systems involved in processing empathy, but it seems to play an important role in the processes. It would be a mistake to characterize the role of the MNS as solely for processing motor actions in a concrete and mechanical sense. Although this system does activate for observed, executed, and imitated actions, there is a complex integration between this system and other areas involved in perspective taking in order to viscerally feel empathy. One way of empathizing is through simulating the facial and bodily expressions of other people; in fact, those who spontaneously imitate others also tend to be more empathic (Chartrand & Bargh, 1999).

Indeed, the MNS has been implicated in both cognitive (for a review, see Kilroy et al., 2017) and emotional (for a review, see Dvash & Shamay-Tsoory, 2014) empathy models in collaboration with areas of the limbic system (i.e., the insula and amygdala). The MNS plays a role in processing the *intentions* of others' motor actions (Avenanti et al., 2013), particularly in social contexts (Gallese et al. 2004), and in emotional contagion—the phenomenon of having another person's emotions trigger similar emotions in the observer (Keysers & Gazzola, 2006). Several studies show that increased IFGop activity is associated with increased cognitive empathy ability (Kaplan & Iacoboni, 2006; Gazzola et al., 2006; Jackson et al., 2005). Numerous studies have also reported that the MNS is engaged in simulation of basic and complex emotions (Blakemore et al., 2005; Ebisch et al., 2008; Jabbi et al., 2007; Singer, 2006; Wicker et al., 2003).

A common self-report tool for empathy is the Interpersonal Reactivity Index (IRI; Davis, 1980), which has been used in many research studies in connection with MNS activation. During an observation task of disgusted facial expressions, activation of the IFG and the insula (a primary area for integration of visceral bodily state information and felt emotion) were correlated with higher empathy scores on the IRI (Jabbi et al., 2007). They found that empathy skills associated with both the ability to imaginatively transpose the self into feelings of fictional characters as well as in higher personal distress experienced in response to others' negative emotions were correlated with the strongest activation of the IFG and insula. Empathic concern measured by the IRI has been correlated with IFG activity in observation of painful facial expression (Saarela et al., 2007).

Interestingly, meta-analysis has indicated that the degree of activation of neural responses depends on the participant's real-time empathy during a task, further supporting simulation of felt emotion in MNS regions (Lamm et al., 2011). These responses are not limited to action observation and can be seen in response to other modalities that require imagery and prior knowledge such as auditory stimuli (Van Overwalle & Baetens, 2009). It is important to point out that in some cases MNS involvement in empathic processes has not been demonstrated (Fan et al., 2010).

Although the exact role and function in empathy needs further research, the sizable evidence cited here indicates an association between the MNS and empathic processing, though context and meaning may be important factors to consider (Aziz-Zadeh et al., 2018). Outside of mirror neurons in particular, the larger simulation or action-perception model of empathy offers a few key advantages other models. Simulation automatically, and therefore efficiently, uses internal motor knowledge to identify others' behaviors, it can explain imitation of motor to social information integration, and it can be used at an early stage of development, facilitating learning of several social and behavioral processes (Ferrari & Coudé, 2018).

Learning Is Embodied

How does the MNS relate to learning? Observational learning is one of the most basic mechanisms by which humans learn (Browder et al., 1986). Cognitive load theory proposes that human cognition is predisposed to learning by observing and imitating others; therefore, these strategies are optimal tools to use for acquiring and communicating knowledge (Sweller, 2010). Due to the fact that the MNS also responds robustly to observation and imitation of face and hand actions (Caspers et al., 2010), watching a teacher or another student demonstrate a skill and then imitating or executing it should allow for higher-quality understanding than, for example, only reading or hearing an explanation. Due to prior data indicating that the MNS is more active when observing videos of actions compared with still images of actions (Furl et al., 2015), this may imply greater effectiveness for use of dynamic rather than static visualizations. In fact, a meta-analysis found the use of dynamic visualizations to be more fruitful for learning outcomes, especially when animations were representational, realistic, and procedural-motor knowledge was involved (Höffler & Leutner, 2007).

Furthermore, the goal-directed nature of an action impacts the strength of activation of the MNS (Gazzola et al., 2007). In this way, it may be easier to understand educational concepts when goal-directed human movement is used to illustrate the concept. For example, a visual demonstration of subtraction might be best understood by a student if they watch a teacher or partner physically remove items from a group to represent subtracting a number of items, rather than seeing a picture of a group of items and then seeing a second picture of fewer items to imply subtraction. In that example, the goal-directed movement of a human action would more strongly activate the MNS. If the students were then to physically reenact these scenarios themselves, it would reactivate this system further, and strengthen the knowledge gained. Thus, observing others perform actions with the intent to imitate themselves, and then subsequent imitation or emulation, would strongly foster learning.

In addition, students need to understand the goals of both the teacher and the lesson in order for the MNS to be engaged effectively. This requires communication with students in order to have appropriate context for the information being covered, as well as an understanding of the intentions of the teacher (Immordino-Yang, 2009). Finally, the MNS is thought to be more active during contexts that are meaningful to the observer (Aziz-Zadeh et al., 2018), so integrating the lesson into a meaningful narrative for the student may also be beneficial.

Kontra and colleagues (2012) reveal how support for the embodied cognition model points to action experience as a powerful tool for learning. That is, if even abstract mental concepts can activate sensorimotor representations in the brain (Lakoff & Johnson, 1999)—and we know that imitation learning is a powerful form of learning—then lessons that engage the student at a sensorimotor level may prove to be more powerful forms of learning than traditional "behind-the-desk" methods (Kontra et al., 2012).

Keysers and colleagues (2018) address this topic in a review of neuromodulation and lesions studies, summarizing how the results of regions associated with the MNS contribute to the topic of embodied cognition. In their review, they reported large themes that are relevant for questions about how we learn and shape the meaning of social and motor actions. First, there is substantial evidence that undermining embodied representation by disrupting PM, SI, or

IPL impairs action prediction and the ability to coordinate action with others, a necessary skill for sensorimotor learning. Second, interrupting any of those areas (PM, SI, or IPL), or primary emotional processing areas like the insula or cingulate, decreases emotion recognition from facial and bodily expressions, which underlie the development of emotion understanding and social communication learning. Third, when *any* of the previously listed regions were disturbed (with a lesion or transcranial magnetic stimulation), it influenced the entire network of regions, lowering the activation of all other nodes in this network when one node was perturbed. The authors interpreted these findings to suggest that (1) embodied representations are inherently sensorimotor, (2) embodied representations are essential for processing and interacting with others, and (3) areas including putative MNS regions are working in a network to achieve motor and social understanding, and all regions are needed to achieve desired outcomes (Keysers et al., 2018).

Learning Is Emotion-Dependent

Just as the MNS uses embodied simulation to code and understand actions, other areas of the brain represent signals from the body to interpret feeling states and guide behavior. Social experiences create peripheral responses in the body, and these somatic representations facilitate feeling states, understanding, and prediction of actions of others (Damasio, 1996).

Immordino-Yang & Damasio (2007) review what patients with frontal lobe damage reveal about the interdependence of emotion and cognition. The evidence in these individuals demonstrates that learning, attention, memory, and decision making all rely on emotion processing. The authors go on to suggest that if emotion processing is a large component of learning, then asking students in school settings to focus on academic skills without attending to emotions is a near impossibility. Even more so, it does a disservice to students by emphasizing skills that will not transfer in a meaningful way to settings outside the classroom (Immordino-Yang & Damasio, 2007). The notion that learning requires personal emotional relevance has important implications for the classroom setting.

Indeed, the MNS may also have strong connections with reward circuits, which may be activated by positive emotions (Aziz-Zadeh et al., 2018). In general, when students perceive greater social emotional support from their teachers, they report greater enjoyment, hope, and pride (Titsworth et al., 2013) as well as better academic outcomes (Korpershoek et al., 2016). Creating an environment that feels emotionally supportive may be important, and perhaps may require an explicit focus on understanding emotions. Students are more likely to benefit from socioemotional learning interventions that are embedded in school culture across all staff and students, are consistently present in all environments including hallways and playgrounds, and have invited parental involvement (Farrington & Ttofi, 2009; Sugai & Horner, 2014; Wilson et al., 2008). Academic and socioemotional skills develop and perform together; therefore, lessons can be designed to promote both skills simultaneously. For example, programs can ground socioemotional lessons into course content through literature and social studies (e.g., Jones et al, 2014; Barr et al., 2015). Learning may be at its best when students can connect their academic skills to abstract, personal, and meaningful experiences (Immordino-Yang & Damasio, 2007) and educators are faced with the challenge of finding new ways to do so in each classroom.

Conclusion

In summary, the human MNS is thought to help process other people's actions and intentions, support motor and social imitation, and may contribute to our felt experience of the emotions of others through embodied simulation. This chapter reviewed how MNS regions, along with other neural networks, may contribute to better sensorimotor and socioemotional learning processes. It also supports classroom use of imitation learning, an emphasis on embodied learning strategies, and attention to social and emotional learning.

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Movement Matters

How Embodied Cognition Informs Teaching and Learning

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