Chapter XIX
The Human Mirror Neuron System

David B. Newlin
RTI International, USA

ABSTRACT

Following the discovery in Rhesus monkeys of "mirror neurons" that fire during both execution and observation of motor behavior, human studies have documented a fronto-parietal mirror neuron system (MNS) with apparently similar functions. We discuss some issues related to the human research, including measurement with neuroimaging techniques and recent neurotechnologies for manipulating regional brain function. We note the remarkable overlap between several brain systems studied in people: the MNS, the Theory of Mind (ToM), the "self"-system of the brain, and the neural "default mode." The functional architecture of these systems may have important implications for how the MNS is organized and its functions. We propose that "auto-mirroring" in which self-observation of one's own motor behavior can be either facilitated or blocked, may be a fundamental aspect of the MNS. Finally, the implications of hemispheric asymmetry in the right and left MNS are discussed. Although MNS research is in its infancy, it bears promise to reveal basic aspects of the brain's functional architecture.

Despite impressive gains in understanding the brain, fundamental questions concerning brain organization and function remain unanswered, unresolved, or highly controversial. This is not surprising given the enormous complexity of neural processes. In this discussion we will focus on one brain system that may be particularly important for human functioning: mirror neurons or the mirror neuron system (MNS). The MNS is a fronto-parietal brain system that is activated when an individual performs a specific behavior <u>and</u> observes that same function being performed by another person. In other words, the MNS is sensitive to the "mirroring" of one's behavior in other people. Even though the discovery of mirror neurons is relatively recent (Gallese et al., 1996), there is now a significant body of research, both human and nonhuman primate , providing evidence that the MNS is an important characteristic of brain organization (Gallese & Goldman, 1998; Oberman & Ramachandran, 2007; Rizzolatti & Craighero, 2004).

Discovery. The remarkable discovery of mirror neurons was made in Rhesus monkeys—entirely inadvertently. Gallese et al. (1996) were studying the electrophysiology of the premotor cortex in macaques when they noticed that the same neurons that were active when the monkeys performed simple behaviors were also stimulated when the animals saw other monkeys or humans doing the same thing they were doing. More recent research has extended this finding to the human brain using neuroimaging techniques, primarily functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and neurotechnologies such as transcranial magnetic stimulation (TMS).

The existence of mirror neurons in Rhesus monkeys and the MNS in humans has raised many important questions about the function(s) of this brain system. Ideas about the functions of the MNS have ranged from the neural substrate of imitative learning (in humans), empathy, reciprocity in human relations, the brain's foundation for social interaction, the kernel of language, understanding the intentions of the behavior of others through internal simulation, and even to the nature of consciousness. Of course, these functions are not mutually exclusive. The ultimate limits of the importance of the MNS have not been delineated despite intensive research, both human and animal, over the last decade. However, recent critiques of the human MNS literature (Dinstein et al, 2008; Turella et al., in press), particularly fMRI studies, have raised questions about whether mirror neurons in monkeys are really homologous in function with the MNS in people.

Purpose. The purpose of this discussion is to explore the MNS literature, integrate it with other information concerning brain function, particularly prefrontal executive functions, and begin to develop models of how the MNS may function as part of control systems in the brain. Better understanding of the MNS may inform the design and implementation of control systems for autonomous agents such as robots.

To presage our conclusions, we—as have others—argue that the MNS is particularly important in social processes that involve gauging the intentions of others and predicting their behavior as it relates to our own. This is one of the fundamental functions of the "self" system of the brain. Moreover, it has immediate implications for the design of robotic systems. Autonomous agents may move closer to having a "self" when they incorporate aspects of the MNS in their control systems. The construction of "self" in human and robotic systems has been somewhat of a "Holy Grail" for a long time.

Multi-agent societies. This discussion focuses on intrapsychic processes and dyadic interactions primarily because the literature, whether animal or human, has not progressed beyond this level. Discoveries of mirror neurons and the MNS in humans have broad implications for social interaction in small groups and in larger multi-agent societies. Whether the MNS chiefly supports imitative learning or internal gauging of the motivations and behavioral proclivities of others (or both), these are inherently social processes. These functions can and may provide the foundation for social processes that would be difficult to conceptualize or study without recourse to a system such as the MNS.

The same arguments apply to robotic autonomous agents and their interactions with other robots or with humans. The spread of information in a multi-agent society and the coordination of communication and behavior among autonomous agents require some internal mechanism roughly comparable to the MNS. In fact, MNS-like systems have been incorporated in autonomous agents using neural network software (see Oztop et al., 2006 for a review). One next step is to study social interaction in robotic systems that have simulated MNSs in their control systems. This will require careful consideration of the proposed architecture of the MNS in humans, the limitations and critiques of this literature, and experimentation that is cognizant of these factors.

THE FRONTO-PARIETAL MNS

Mirror neurons have been measured typically with single-cell electrophysiology in monkeys (Gallese & Goldman, 1998). The primary regions of mirror neurons studied in the Rhesus monkey are the ventral