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# Understanding Neural Mechanisms of Action Observation for Improving Human Motor Skill Acquisition

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#### Abstract

Action observation is a useful approach for improving human motor skill acquisition. This process involves the mirror neuron system that consists of the ventral premotor area, inferior parietal lobule, and superior temporal sulcus. The interaction between these areas produces the effect of action observation. This chapter presents neurophysiological and brain imaging studies of action observation, and their application to human motor learning. For action observation, the mirror system appears to map the intention in the ventral premotor area and the goal in the inferior parietal lobule. These features of action representation may be useful for refining conditions of practice, based on the mirror system, for acquiring new motor skills.

**Keywords:** action observation, electroencephalography, mirror neuron system, motor learning

# 1. Introduction

Previous neurophysiological and brain imaging studies have revealed that neural activity associated with observation of another person's movement was elicited in the motor-related cortical areas [1–3]. The motor-related cortical areas that get active during such motion perception, constitute the mirror neuron system. Characteristically, this system is activated not only when a person performs a goal-oriented movement by himself/herself, but also when the person observes the same movement performed by others (**Figure 1**) [4]. Action observation automatically creates a similar simulation of movement in the brain of the observer [5, 6]. In other words, action observation induces functional reorganization of the brain, and facilitates



© 2017 The Author(s). Licensee InTech. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. [cc] BY motor learning via the mirror neuron system (**Figure 2**) [7, 8]. Thus, observation of another person's actions and behavior alters the neuronal activity of the observer. This chapter discusses neurophysiological and brain imaging studies of action observation, and their application to human motor learning.



**Figure 1.** Mirror neurons in monkeys [4]. Top indicates the neural activity in area F5 when the monkey grasps food. Bottom indicates the neural activity in are F5 when the monkey observes the human grasping food.



**Figure 2.** Mirror neuron system in humans [7]. Purple areas (PMD and SPL) are involved in reaching movements. Yellow areas (IFG, PMV, IPL and IPS) are involved in transitive distal movements. Blue areas (STS) are involved in observation of upper-limb movements. Green areas (A) are involved in intransitive movements. Orange areas (B) are involved in tool use. PMD indicates dorsal premotor cortex; SPL, superior parietal lobule; IFG, inferior frontal gyrus; PMV, ventral premotor cortex; IPL, inferior parietal lobule; IPS, intraparietal sulcus; STS, superior temporal sulcus.

# 2. Neural mechanism of action observation

The mirror neuron system is concerned with the neural mechanism of action observation. The mirror neuron system is a neural system that consists of the ventral premotor area, inferior parietal lobule, and superior temporal sulcus, and the interaction between these areas produces the effect of action observation (**Figure 3**) [9]. The mirror neuron system converts sensory information obtained through observation to a specific motion pattern, which is an objective [10]. Thus, decryption of the action and behavior of other individuals are facilitated. Additionally, the encoding of the meaning and objective of an action facilitates understanding of the purpose of the action performed by others, internally, without requiring higher cognitive processes, such as reasoning. The understanding of other's intentions [11], empathy [12], and theory of mind [13] are known functional characteristics of the mirror neuron system, and dysfunction of the mirror neuron system is associated with autism [14].

Fadiga et al. investigated the mirror neuron system using transcranial magnetic stimulation (TMS) [5]. They measured the motor evoked potential (MEP), which is the index of excitatory change of the corticospinal tract, from finger muscles, by stimulating the motor area by means of TMS, while the subject was observing the action. The results showed that the MEP amplitude of the finger muscle involved in the observed action, increased significantly, and these phenomena were not observed in the MEP amplitude of another finger muscle that was not concerned with the observed action. Thus, the peripheral motor system also prepares for performing the observed action, and the temporal consistency between the muscle group concerned with the action that is an objective and the muscle activation patterns indicate that the mirror neuron system couples action execution and observation; this indicates the possibility that the reorganization of the motor system network that is induced by action observation and that which is induced by actual physical practice involve the same mechanisms [16].



**Figure 3.** ALE meta-analysis of action observation in the human brain [9]. Significant meta-analysis results for action observation, summarized over all effectors. All results are displayed on the left and right lateral surface view of the MNI single subject template.

Many previous studies have investigated the excitatory changes in the corticospinal tract during a single action observation, and some of these have examined the excitatory change in the corticospinal tract during repetitive action observation. Stefan et al. revealed that repetitive action observation changes the motor representation in the cerebral cortex as it does with physical practice [17]. Moreover, they disclosed that these changes of the motor representation in the cerebral cortex, were induced by physical practice along with brief action observation. Furthermore, it has been reported that repetitive action observation increased the excitability of the corticospinal tract, and that there was a significant positive correlation between the increased excitability of the corticospinal tract and the change in motion patterns [16].

Watanabe et al. examined the effect of observation viewpoint on brain activity and performance [18]. There are two observation perspectives. One involves observing another person's action from the same side as that of the subject's perspective, termed the "first-person perspective" and the other involves observing the other person's action on the opposite side as that of the subject's perspective, termed the "third-person perspective" (**Figure 4**). Their study investigated the difference between reaction time and brain activity from first-person and third-person perspectives, while the subject observed the action and imitated the action of another, using functional magnetic resonance imaging (fMRI). They showed that the motor-related areas involve the mirror neuron system, including the ventral premotor area, supramarginal gyrus, and supplementary motor area, in the first-person perspective significantly more than in the third-person perspective. Thus, action observation from the first-person perspective activates the mirror neuron system advantageously, and facilitates the intracerebral simulation of the action that is the objective, and enhances motor learning. This information should be applied to motor learning, considering the various conditions of action observation.



Figure 4. First-person perspective (left) and third-person perspective (right).

### 3. Mirror neuron system and EEG studies

Many studies have investigated the mirror neuron system using electroencephalography (EEG) [19]. A specific EEG rhythm, called the mu rhythm (8–13 Hz), is observed in the human senso-rimotor cortex [20]. The characteristics of the mu rhythm are blocked during actual movement

[20] as well as observation of action [21] and motor imagery [22]. Therefore, numerous EEG studies have used the mu rhythm as an electrophysiological marker of the mirror neuron system in humans, after Altschuler et al. [23] first investigated this possibility. Those studies found that the mu rhythm represents the activity of the mirror mechanism in humans. An fMRI study also showed a significant correlation between mu rhythm desynchronization (**Figure 5**) [24] and BOLD activity in typical mirror neuron system regions.

Many studies have examined the reactivity of the mu rhythm during action observation. Avanzini et al. [25] investigated the dynamics of sensorimotor cortical oscillations during



**Figure 5.** Mu rhythm desynchronization [24]. Simulation of mu rhythm desynchronization in the 8–13 Hz frequency band. There is a decrease in amplitude in the electroencephalogram from baseline during action observation or execution.



**Figure 6.** EEG rhythms during action observation [25]. The graph shows the EEG power time-course for each frequency band: alpha band (8–13 Hz) in green, lower beta (13–18 Hz) in red, and upper beta (18–25 Hz) in cyan.

the observation of hand movements using EEG (**Figure 6**). A desynchronization of alpha and beta rhythms was observed in the central and parietal regions. Notably, there was a large post-stimulus power rebound present in all bands. Furthermore, the velocity profile of the observed movement and beta band modulation correlated, indicating a direct matching of the stimulus parameter to motor activity.

#### 4. Action observation and motor learning

Schmidt defined that motor learning is a "process of acquiring the capability for producing skilled actions" [26], and "the changes associated with practice and experiences, in an internal process that determines a person's capability for producing motor skill" [27]. Moreover, Guthrie stated that motor learning is a "relatively permanent change, resulting from practice or a novel experience, in the capability for responding" [28]. In other words, motor learning is



**Figure 7.** Cortical activation patterns in the action observation (AO), motor imagery (MI), and control (C) groups [34]. Average TRPow (task-related power) changes with respect to resting baseline, within the two frequency bands showing significant group effects, were interpolated and projected onto an average brain cortical surface.

the capability acquired from practice and experience, and the change is relatively permanent. How can then action observation contribute to motor learning?

Motor imagery is similar to action observation. It is the mental simulation of movement without physical movement of body parts [29]. Action observation and motor imagery have been shown to share the same neural basis as that used for the execution of the actual physical movement [30]. However, the process of action observation and motor imagery are different. Action observation is a bottom-up process (process from perception), while motor imagery is a top-down process (process from memory). Nevertheless, these processes are not clearly divided, and a feed-forward model was constructed by complementing these processes [31]. In addition, action observation has an effect of promoting motor imagery [32].

In the early stages of new complex motor learning, action observation is superior to motor imagery as a strategy for motor learning, as revealed by behavioral [33] and EEG data (**Figure 7**) [34]. Motor imagery is influenced by the environment and personal imaging ability and requires mental effort. In contrast, action observation is easier to apply than motor imagery, despite targeting activation of the same neural network as motor imagery [35]. We have also reported that the left sensorimotor and parietal areas of the high-motor learning group showed a greater decrease in the alpha-2 and beta-2 rhythms than those of the low-motor learning group during observation and execution. These results suggested that the decreases in the alpha-2 rhythms in these areas during observation and execution.



**Figure 8.** Changes in EEG activity durings observation and execution of a motor learning task [36]. Alpha-2 (A) and beta-2 (B) rhythms in the left sensorimotor and parietal areas during action execution from the 1st trial to the 5th trial were significantly decreased in the high-motor learning group compared with in the low-motor learning group.

are associated with motor skill improvement (**Figure 8**) [36]. Accordingly, action observation may be an effective tool as an intervention method during the early stage of motor learning.

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