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**REVIEWS**

# Cognitive Motor Rehabilitation: Imagination and Observation of Motor Actions

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**Abstract**—Motor rehabilitation can be considered as a learning process in which lost skills should be restored, and new ones should be acquired on the basis of physical training. But is exercise always necessary to achieve these goals? Many authors have shown that motor imagery and observation lead to the activation of the same brain areas as their physical counterparts, and that they can cause the same plastic changes in the motor system as real physical training. The review presents data on the use of motor imagery and observation as a substitute for physical action in motor rehabilitation, on the community of their neural substrates, as well as on the behavioral and neurophysiological use of these methods in healthy people and in clinical practice.

**Keywords**: movements, motor actions, training, rehabilitation, motor images, movement imagination, action observation

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Is it possible to learn how to perform a real movement (or motor action) by mental simulation or by observing its execution? The answer to this question is important not only from the theoretical point of view, it also has a clinical significance: when patients are unable or have no possibility to move, they could train mentally to prevent unwanted cerebral changes resulting from inactivity and nonuse of limbs and, in addition, such training could play the role of an additional tool in motor learning [1].

"In the field of human motor cognition, it was only recently realized that actions contain a latent stage. This stage is a representation, which includes the goal of the action, the means of achieving it, its consequences for the body and the external world" [2]. In accordance with this postulate, action imagination and action observation are mental states that, in their content (the set of operations necessary for their implementation) and structure (the set of brain regions involved in their formation), are similar to real action.

There is strong evidence that observation of action execution by other people and motor imagery (imaginary movements) can increase the effectiveness of motor training and/or motor recovery [3–8]. Researchers believe that these positive influences are associated with the fact that action observation and imagination activate the same neural substrates that are activated during physical execution of the same action [2, 9, 10].

## MOTOR IMAGES (IMAGINARY MOVEMENTS)

**Mental training.** Motor images are a cognitive process in which a person imagines that he is performing a movement (action) without performing it physically; it is a dynamic state during which motor action presentation is internally activated without any motor output [1]. Motor image [11], imaginary movements [4], mental representation of movement or mental image of movement [12] are different names for the same phenomenon, which is considered as a mental imitation of real (physical) movement [13]. The coincidence of many of their behavioral and neurophysiological characteristics led to the concept of functional equivalence of real and imaginary movements [14].

Mental training using motor imagery is a process in which a person mentally simulates movements repeatedly to improve their physical execution [15]. It is one of the methods of acquiring and reinforcing motor skills [11], which improves various elements of motor behavior [16]. However, its effectiveness is lower than that of physical training [17].

Motor imagery is also an element of a therapeutic technique, a method in which motor imagery is repeated several times in order to rehabilitate motor functions [18]. It is a safe and inexpensive technique that can be used by the patient himself without medical supervision [15]. It can be used as an adjunct to physical training or as a substitute for them when the patient's motor abilities are limited [19]. The results of the application of this method are described in [14, 20]; however, its clinical efficacy should still be interpreted with caution [15, 21]. Although the effectiveness of mental training is lower than the effectiveness of physical training, their combination produces a greater effect in motor learning and rehabilitation than their use separately [19].

The theoretical basis of mental training is data on the functional equivalence of real and imaginary movements [14, 18].

**Plastic changes.** Motor rehabilitation strategies are based on the concept of central nervous system (CNS) plasticity, which is facilitated by early, intensive, and targeted therapy [22]. It is suggested that motor imagery leads to stimulation of the motor regions of the brain, thereby contributing to their adaptive modifications [21, 23]. Motor imagery training induces changes in cortical motor areas similar to those that occur as a result of physical training [24]. Neuroplasticity initiated by mental practice and providing an opportunity to improve the quality of motor actions is shown using tomography in healthy individuals [25]. The data obtained using transcranial magnetic stimulation indicate a functional relationship between cortical reorganization and changes in motor behavior [25].

The patterns of activity of the brain structures during imagination and execution of real movements in patients with stroke, Parkinson's disease, with spinal cord injuries and with limb amputation differ from the patterns of healthy individuals, but the functional equivalence between imaginary and real movements is preserved [18]. In addition, in patients of these clinical populations, mental practice is accompanied by an increase in motor imagery ability [18].

With regard to plastic changes caused by mental training, one should pay attention to the results in the studies [26, 27]. According to [26], mental training "literally reversed" the cortical reorganization caused by amputation. A similar result was observed in [27], where mental training was conducted for patients with spinal cord injuries.

**Behavioral and neurophysiological data.** The ability to mentally perform movements appears at the age of five [28], improves in adolescence and early adulthood [29], but worsens over the years. It weakens to a lesser extent for simple than for complex movements, and the weakening is less significant for everyday motor acts than for tests used in laboratory studies [30]. People differ from each other in their ability to imagine motor acts [31]. This ability increases as a result of mental or physical practice and decreases as a result of loss or disuse of limbs [32].

According to [31], the patterns of cerebral activity in young people with low and high motor imagery ability differed from each other. They also differed among beginners and professional athletes when imagining the same motor act, and mental training helped to eliminate this difference [33].

Movement imagination can be performed either from the first- or third-person perspective. In the first case, a person mentally reproduces what he saw (or felt) when he performed the movement himself. In the second case, a person acts as an observer: he mentally sees the one who performs a given movement, regardless of whether he sees himself or another person [34].

Imaginary movements from the first-person perspective have a pronounced functional equivalence with real movements, compared to movements formed from the third-person perspective [35]. Kinesthetic motor images (i.e., imaginary movements formed on the basis of mental simulation of kinesthetic sensations accompanying real movement) activate the motor regions of the brain to a greater extent than visual images (i.e., motor imagery based on mental movement visualization) [36]. The kinesthetic motor image of lower limb movements, in contrast to the visual one, influences the parameters of postural activity [37].

The activity of the autonomic nervous system changes during movement imagination, and these changes are similar to those observed during the execution of the same movement (although they are less marked) [38]. Therefore, autonomic parameters can be used to control the process of motor imagery [39].

During movement imagination, electroencephalographic activity also changes. In particular, there is a desynchronization of the sensorimotor rhythm (μ-rhythm) in the cortical representations of the limb performing the movement [4, 40], as well as the limb the movement of which is imagined [40].

The inconsistency of the results of studies in which the influence of motor imagery on spinal motoneurons may have been related to the fact that a number of conditions must be fulfilled to reveal these influences. First, real-time control of the quality of the imagination task is required. Second, it is necessary to assess the motor imagery vividness, an indicator of an individual's motor imagery ability (especially since it has been shown that the greater the motor image vividness, the greater the corticospinal facilitation [41]). Therefore, a negative (with respect to the effect on motoneurons) result may simply be a consequence of weak corticospinal facilitation evoked by motor imagery in the examined group of people. Third, motor imagery is a dynamic process [33, 40]. Therefore, the test result depends on the point of time when the test stimulus is applied. Fourth, motor imagery is a process realized by means of working memory [42, 43]. Consequently, the testing result also depends on the interval between the real and mental movement. It should be noted that these suggestions about the necessary conditions directly follow from the comparison between studies [39, 40, 44, 45], the authors of one of which [44] did not find the effect of motor imagery on spinal motoneurons.

## MOTOR ACTION OBSERVATION

**Mirror neurons.** Neurons that discharge both when performing a motor act and while observing how others perform it are called mirror neurons [46–48]. They were detected in macaques in the ventral premotor $F_5$ area and among the neurons of the inferior parietal lobules, and the network containing these neurons was called the “mirror neural system” [49]. However, according to [9], it was shown that neurons in the dorsal premotor cortex, in the supplementary motor area, in the primary motor cortex, in the upper and middle parietal, in the intraparietal and parieto-occipital regions of the cortex can respond to both observation and execution of an action. A wider network of neurons participating in action observation is sometimes called an action observation network [9].

Due to the invasiveness of recording the activity of individual neurons, there is very little direct evidence of the presence of mirror neurons in the human brain. In the overwhelming majority of studies (with the exception of [50]), indirect methods were used to detect them: functional magnetic resonance imaging (fMRI), EEG, and transcranial magnetic stimulation (TMS). However, there is ample evidence that simple movement observation causes changes in the human motor system, and this phenomenon is taken as evidence of some form of coupling of action observation and execution in the human brain [51].

Mukamel et al. [50] recorded the activity of single neurons in the medial frontal and temporal areas of the cortex, while the patients took various objects with their hands or observed the same actions executed by other patients. A significant proportion of neurons in the supplementary motor area, as well as in the hippocampus, responded to both observation and execution of such actions. A subset of these neurons showed activation during the execution of an action and inhibition during its observation [50].

Action observation recruits representations that arise through automatic visuomotor transformations called almost interchangeably, namely, “motor imitation, motor resonance,” or “mirror mechanism” [52]. The mirror mechanism is characterized as “... a mechanism that transforms sensory representations of the actions of others into motor representations of the same actions in the observer’s brain” [53]. “...whenever people observe an action performed by someone else, a set of neurons providing the observed action is activated in their motor system” [54].

**Behavioral and neurophysiological data**. According to [51], action observation induces an early nonspecific facilitation of corticospinal excitability (approximately 90 ms after the beginning of observation) followed by a later modulation of activity specific to the muscles involved in the observed action (after 200 ms).

The set of motor areas activated during action observation depends on their complexity [55] and the individual motor experience of the observer [56]. The observation of a complex action involves more areas than the observation of a simple one [55]. The type of observed action can also influence cerebral activation: higher activation was found during transient actions than during intransient ones [57]. Familiarity with motor actions determined by how often they are performed or observed increases the recruitment of mirror neurons not only during transitive [56], but also during intransitive movements [58].

Observing the actions executed by different effectors activates different areas of the premotor and parietal cortex [59]. Therefore, the effector-associated somatotopic activation pattern is present not only during physical execution and imagination of movement, but also during its observation.

The first results of studies in monkeys showed that mirror neurons only respond to object-oriented action observation and execution, but not to observation of aimless movements or actions performed with tools [60]. However, according to [9], data on the activity of mirror neurons in these animals obtained later showed the following: the presence of an object is not necessary; actions performed with tools affect mirror neurons; observation of aimless, nonobject-directed movements of the forelimbs is also effective. In addition, according to [61], although it was believed that only observations of the actions of biological objects activate the network of mirror neurons, later studies showed its sensitivity to the observation of the actions of nonbiological objects.

Action observation from the first-person perspective causes a stronger activation of the cerebral areas than observation from the third-person perspective [62]. When the action is observed from the first-person perspective, the strongest suppression of the μ-rhythm also occurs [63]. Significant μ-desynchronization during action observation is discussed in [64].

**Learning by observing.** Observing someone else’s action to master a new movement is a common practice in adult life, e.g., in sports, and is a common procedure for developing motor skills in childhood [65].

Based on the existing experimental data, it can be stated that action observation can be regarded as a kind of motor priming, since it can facilitate the execution of the same movement (action) by the observer [1]. Action observation is a technique that facilitates the emergence of neural plasticity by activating the mirror neural system [66].

Volunteers who observed a person learning to move in an unusual power environment performed significantly better on subsequent testing in the same environment than those who did not observe action under unusual conditions [67]. Proprioceptive sensitivity training improved the results of subsequent learning by observation, which indicates the involvement of the somatosensory system in such learning [68]. According to [2], action observation automatically triggers its mental simulation and therefore facilitates the subsequent execution of a real action.

The motor system can be influenced not only by visual, but also by other action-associated signals. In humans, motor facilitation during action observation was boosted when action-associated auditory and visual signals were presented simultaneously [69]. These results indicate the possibility of combining visual information with auditory signals in rehabilitation protocols to increase the beneficial effects of action observation training [65].

**The results of the use of action observation in clinical practice.** A novel approach in rehabilitation, known as action observation therapy (or as observation therapy) takes advantage of the mirror mechanism to correct movement disorders [66, 70, 71]. During one typical session, patients observe a routine activity and then perform (or attempt to perform) it [70]. Until now, this approach has been successfully applied in the rehabilitation of upper limb motor functions in stroke patients, in motor rehabilitation of patients with Parkinson's disease, and in children with cerebral palsy; this approach also improved the motor functions of the lower extremities in postoperative orthopedic patients [70].

The use of observation therapy in twenty randomized controlled trials showed that most of these studies imply the effectiveness of observation therapy as an adjunct to conventional physiotherapy to improve motor function recovery in neurological and orthopedic deficit sufferers [71]. Based on an analysis of twelve randomized controlled trials, evidence is presented that action observation is beneficial for improving the upper limb motor function and independent self-care of stroke-afflicted individuals in daily life [66].

Buccino et al. [72] conducted a randomized controlled study with the participation of 18 children with cerebral palsy: 11 watched video clips demonstrating motor actions (observation therapy), and 7 watched video clips without motor actions (control group). Compared with the controls, children who received observation therapy significantly improved the upper limb functional parameters immediately after treatment, and this improvement persisted for two months after treatment. Twelve of the 18 children also underwent functional magnetic resonance imaging before and immediately after treatment. Compared to the control group, children who underwent observation therapy had a stronger activation in the parieto-premotor network during the hand–object interaction immediately after treatment. The results confirm that this therapy promotes reorganization of cerebral networks [72].

## GENERAL NEUROPHYSIOLOGICAL SUBSTRATE FOR MOVEMENT (ACTION) OBSERVATION, MOTOR IMAGERY, AND PHYSICAL EXECUTION

As noted in the previous sections, mental training and observation therapy are based on the evidence that observation, imagery, and physical execution of the same movement (or motor action) cause very similar cerebral activations. This, in particular, is evidenced by the results of meta-analyses performed by different authors.

In a meta-analysis [73], it was shown that similar groups of cerebral regions are activated in three different situations (observation, imagery, and execution of the same movement (action)), which supports the hypothesis of the functional equivalence of observation, imagery, and physical execution of the same actions. However, *this equivalence is not strict* if we take into account the incomplete coincidence of domains in different groups [73]. The results of meta-analyses performed later [74–77] generally confirmed these conclusions.

Meta-analyses are more statistically powerful than separate studies, because they allow data from multiple studies to be combined [76]. The problem is related to the variety of motor tasks in various studies, which range from very simple movements to complex motor actions [76] the problem is even wider: simple movements are usually used in the case of their physical implementation (due to limitations in the tomograph scanner), while more complex motor actions are used when they are imagined and observed [78]. In addition, the results of meta-analyses also depend on the selection criteria for the studies included in the analysis. Therefore, the conclusion based on the results of meta-analyses about the existence of complexes (groups) of cerebral regions, which are the same for imagery, observation, and execution, does not mean at all that the composition of these complexes will always be the same, for example, when performing different tasks. This is evidenced, in particular, by the data obtained by the authors [76] who first performed a general meta-analysis of 75 studies that studied motor imagery and then conducted additional meta-analyses of these studies using different inclusion criteria. It appeared that the brain areas activated by motor imagery depend on the type of movement to be imagined (simple or complex), the modality of the image (kinesthetic or visual), the effector (part of the body involved in the movement), and the instruction given to the subject [76]. Therefore, the meta-analytic information about the composition of the complexes of areas, which are activated in all three discussed situations, is valid only for a certain "average person," "average effector," "average movement," etc. This information is clearly insufficient for the clinician to make an adequate choice between different types of influences (between observations, imagery, physical execution) in the case of specific motor disorders. All the more so, because to date only in two (!) studies that assessed the activity of the whole brain were the cerebral activity data in all three situations obtained from the same individuals during execution of the same tasks [10, 79].

Filimon et al. [79] in a study of 16 healthy volunteers investigated the cortical representations of the physical, observed, and imaginary hand transfer (from the on the chest position) to a certain place in space specified by the position of images of abstract figures that should not be touched. Video clips of a human right hand reaching for the same figures were used during movement observation. The authors revealed cerebral activations common to all three motor tasks, but, in addition, reported that the activations during hand movement observation in their study differed from those known from the literature during movements associated with hand–object interactions. Therefore, it was concluded that responses of the mirror neural system are specific to the type of action performed by the hand [79].

Filimon et al. [9] presented the results of a new data analysis published in 2007. Using the so-called multivoxel analysis of activation patterns, they showed that cerebral representations common to the observed, imaginary, and physical movement of the hand are distributed in both dorsal and ventral premotor and parietal areas of the cerebral cortex, whereas in areas that are coactivated in all three situations, it is possible to identify the task that caused the activation.

P. Simos et al. [10] used fMRI to assess the activation of the brain regions in healthy young individuals during physical execution, observation, and imagery (from the first-person perspective) of visually guided tracing with the right index finger of the sides of an invisible equilateral triangle that was carved on a board positioned on the subject's chest and which he could not see. When he was physically performing an action, the subject had to circle with his index finger that side of this triangle, which was signaled by a light spot flashing on the screen in one of three positions corresponding to the apices of an invisible equilateral triangle. When performing a motor imagery task, the subjects had to mentally move their index finger to the apices of the triangle, the position of which was signaled by flashes of light on the screen. When performing the action observation task, the subjects watched (without moving their eyes and fingers) how the image of another person's hand traces the sides of an invisible triangle on the screen in accordance with flashes of light. As a result of the study, activations of groups of cortical areas were identified that were the same for all three discussed situations, and the analysis of functional connections made it possible to conclude that the general sensorimotor frontoparietotemporal cortical network is recruited for execution, observation, and imagery of the same actions [10].

According to the data obtained in [10], the areas of the brain activated during the execution of all three tasks included the representation of the upper limb in the primary motor and somatosensory cortex, the dorsal and ventral premotor cortex, BA8 in the middle frontal gyrus, the superior and the inferior parietal cortex, the posterior part of the superior temporal gyrus (including the temporoparietal node), and the posterior part of the middle temporal gyrus (including the extrastriatal region of the body). Activations common to all three tasks, which did not reach the level of significance, were also found in the dorsal supplementary motor area (SMAd-proper), in the secondary somatosensory cortex, and in the posterior precuneus (BA7).

Activation focuses, unique for physical task execution, were revealed in the left (contralateral to acting arm) ventrolateral thalamus, in the right secondary somatosensory region, in the anterior precuneus and anterior spinocerebellum (lobules IV–VI), as well as in the anterior cerebrocerebellum bilaterally.

Activation focuses unique for observation were found in the left anterior spinocerebellum as well as in BA19 bilaterally. Activation focuses unique for imagery have been found in the right insula and posterior precuneus, in the middle frontal gyrus (BA9/46), mediodorsal thalamus, and inferior frontal gyrus (BA44/45/47) bilaterally, as well as in the anterior part of the left pre-supplementary motor area.

With respect to the presence of similar groups of regions and common cerebral networks involved in all three situations, the study data are consistent with the results of the above meta-analyses. However, they also indicate the differences between these groups. For example, in [10], the primary motor cortex was activated in all three situations discussed; in [79], only during movement execution; in [76], it was not activated during motor imagery; in [74], the primary motor cortex was recruited during action observation only when the participants observed it for the purpose of the subsequent physical simulation. Simos et al. [10] also reported activations common to only two tasks (physical execution–observation, physical execution–imagery). It should be noted that it is precisely this versatile information that experimenters/clinicians need when choosing a method of influencing cerebral structures to correct specific motor disorders.

## CONCLUSIONS

Action imagination and action observation training is generally viewed as two separate techniques that can be used alone or in conjunction with physical training to optimize motor learning and motor rehabilitation. Independent application of these techniques, as follows from this review, showed the feasibility of their use. In addition, there is clear evidence that motor action observation and imagery can induce similar patterns of cerebral activity. Based on these data, researchers have now turned to the study of the results of their combined use [20]. New studies are emerging showing the possible benefits of the use of motor imagery while observing an action. Apparently, this technique is relatively simple for healthy adults and intuitively implies a closer correspondence with a physical action than its simulation only with motor images or only through action observation [36]. Another area of future research is a growing body of evidence from healthy people suggesting that the combination of observation and imagery with central or peripheral noninvasive stimuli may have a greater impact on brain plasticity and motor learning than their use alone [3].

One of the reasons for the special interest in action imagery and observation is that training with their use affects not only the cortical mechanisms of motor control, but also the peripheral nervous networks, since the brain structures involved in the preparation of movement, which is their primary goal, are projected onto the motor areas of the brain and the periphery of the body [20]. However, general conclusions about the effectiveness of such effects are not allowed by the heterogeneity of patient groups, methods of rehabilitation programs, and methods for assessing the motor function recovery. There is another, no less important reason for the ambiguous results. It stems from a lack of basic research data on the processes that make these exercises effective. For example, there is no sufficiently reliable way to control mental execution of a motor task. There is also a lack of data on the cerebral activity patterns in actions, which are different from those traditionally studied: “stretched out his arm and took an object.” But if the responses of the mirror neural system are indeed specific to the type of action being performed, as suggested, in particular, in [79], then it is possible that different movements (or actions) are similar to different drugs, the use of which can only be effective in certain situations. However, information about these hypothetical “mental drugs,” i.e., about the patterns of cerebral activity in different types of movements (actions) is very limited. The information on cerebral activity during observation, imagery, and physical execution of the same motor task by the same people is strikingly scant, although such information is necessary for the clinician to make an adequate choice between different types of influences (between observation, imagery, and execution) in the case of specific movement disorders.

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## COMPLIANCE WITH ETHICAL STANDARDS

The study does not contain any research involving animals or humans.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest connected with the publication of this article.

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