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Mechanisms and research progress of motor imagery combined with action observation in cognitive rehabilitation

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Abstract

Introduction:

Cognitive deficits refer to impairments in the brain's ability to process information, memory, attention, reasoning, decision-making, and other cognitive functions. These deficits are commonly seen in various neurological conditions and after brain injuries, such as stroke, traumatic brain injury, and Alzheimer's disease. Cognitive deficits not only affect the patient's daily life but also lead to emotional distress, social isolation, and a decline in social functioning, placing a significant burden on both patients and their families. Cognitive rehabilitation (CR) is a therapeutic approach aimed at improving cognitive function through various strategies, training, and interventions, ultimately enhancing quality of life.

As such, research in cognitive rehabilitation has attracted global attention from scholars. Motor imagery (MI) and action observation (AO) are key rehabilitation methods in the cognitive domain and have been widely used in related studies. Recently, the combination of motor imagery and action observation therapy (AO+MI) has emerged as a promising research direction, receiving increasing support in the academic community.

Aim of the study:

This study aims to explore the mechanisms behind the combination of action observation and motor imagery (AO+MI) and assess the effectiveness of this innovative approach in cognitive rehabilitation.

Material and methods:

A literature review was conducted by searching databases such as PubMed, Web of Science, and Google Scholar for English-language articles. Keywords including "motor imagery," "action observation," and "cognitive rehabilitation" were used in the search.

Conclusions:

Both motor imagery (MI) and action observation (AO) have demonstrated positive effects on cognitive function. However, the combination of MI and AO may produce three distinct states that require further investigation. Preliminary findings suggest that AO+MI has shown promising results in enhancing corticospinal excitability (CE), benefiting children with developmental coordination disorder (DCD), and improving outcomes in stroke patients. However, some scholars have raised concerns, emphasizing the need for further experimental validation.

Keywords: Motor imagery; action observation; cognitive rehabilitation

Introduction

Cognitive deficits are a prevalent symptom of central nervous system diseases, primarily characterized by memory impairment, difficulty concentrating, executive dysfunction, cognitive decline, and slowed processing speed[1]. Common causes include neurodegenerative diseases, strokes, traumatic brain injuries, and psychiatric disorders. In recent years, advancements in technology and research have led to the application of brain imaging techniques and various neuropsychological assessments in this field. Current treatment methods for cognitive deficits encompass pharmacotherapy, psychotherapy, and cognitive rehabilitation[2]. Notably, motor imagery therapy and action observation therapy play critical roles in cognitive rehabilitation.

Cognitive rehabilitation (CR) is defined as “a therapeutic approach aimed at enhancing the cognitive abilities of individuals with brain injuries to address deficits in perception, memory, and language”[3]. According to the Brain Injury Association of America, cognitive rehabilitation systematically employs medical and therapeutic strategies to improve cognitive function and the daily activities affected by single or multiple cognitive impairments[4]. With the evolution of clinical neuropsychology, cognitive rehabilitation increasingly draws upon neuropsychological research to assess and train individuals with cognitive deficits, which is why it is also referred to as neuropsychological rehabilitation[5]. Research in cognitive rehabilitation focuses on the impact of cognitive impairments on daily living activities, rehabilitation intervention methods, and mechanisms of effectiveness.

Cognitive rehabilitation training involves the process of relearning cognitive functions following brain injury, including retraining basic skills and applying educational and training outcomes to everyday life to enhance functional abilities[6].

Motor imagery (MI) is a process that activates brain areas associated with movement through the mental simulation of actions[7], During motor imagery, individuals envision themselves performing specific actions without physically executing them or engaging any muscles [8]. This represents a dynamic state where movement is represented through internal activation. Subjects simulate both the visual and motor aspects of an action by imagining themselves carrying it out, yet they do not perform any actual movements[9]. In other words, motor imagery requires the conscious activation of brain regions responsible for movement preparation and execution, alongside voluntary inhibition of physical actions[10]. Motor imagery can be categorized into two types: kinesthetic imagery and visual imagery[11]. The perspective utilized for imagery can be either first-person or third-person. In kinesthetic imagery, subjects immerse themselves in the imagined scenario, representing a dynamic experience. Conversely, in visual imagery, subjects observe themselves or another individual acting from a distance, representing a static experience [12]. Since the third-person perspective can involve three different observation positions, an illustrative diagram is provided for clarification, as depicted in Figure 1.

Figure 1 Schematic diagram of first and third-person

Action Observation (AO) is a process wherein observing others perform specific actions activates neural regions in the observer’s brain that are associated with those same actions. During this process, the observer’s brain activates neural structures as if they were acting themselves, engaging what is known as the mirror neuron system[13].

In the 1990s, Italian neuroscientist Rizzolatti and his team first identified this system through experimental studies. Their research revealed that when monkeys merely observed others performing certain actions, neurons in their premotor cortex—particularly those in the F5 area, which is related to movement planning and control—exhibited firing patterns similar to those generated when the monkeys performed the actions themselves[14]. Subsequent studies identified analogous functional regions in the human brain, which are instrumental in imitation, learning, and understanding the behavior of others [15].

Motor Imagery (MI) Training Combined with Action Observation Therapy (AO+MI) has emerged as an effective neurorehabilitation technique for patients experiencing motor function impairments due to conditions like stroke and brain injury[16].

This therapeutic approach promotes functional recovery by activating motor-related brain regions and harnessing neuroplasticity, the brain's ability to reorganize and adapt [17]. Integrating AO and MI appears to be more effective in enhancing patients' motor functions than applying either method in isolation. AO+MI has been shown to augment neuroplasticity, enhance the efficiency of motor learning and relearning, strengthen muscle control, reduce spasticity, and ultimately improve rehabilitation outcomes and daily living abilities. This approach has garnered increasing attention from researchers in recent years, positioning AO+MI as a pivotal direction for future cognitive rehabilitation research[18]. Consequently, this paper systematically examines the theoretical mechanisms underlying MI, AO, and AO+MI, analyzing the effects and efficacy of AO+MI in the cognitive rehabilitation field. The study aims to contribute to the theoretical framework and serve as a reference point for future research in cognitive rehabilitation.

1 Mechanisms of action of motor imagery and action observation

1.1 A study of the mechanisms of motor imagery

Several scholars have proposed theories and hypotheses related to motor imagery therapy, highlighting various perspectives on the subject. The main theories concerning motor imagery include the following[19]: Psychoneuromuscular Theory asserts that motor imagery activates neural pathways similar to those used in actual movement, leading to neuromuscular activations that are similar, but weaker, than those produced by real movements. Through repeated imagery training, these pathways can be reinforced. Symbolic Learning Theory posits that motor imagery aids individuals in constructing and enhancing cognitive representations of movements. During the imagery process, individuals can repeatedly simulate movements in their minds, resulting in a clearer understanding of the structure of those movements. Bioinformational Theory suggests that motor imagery training is not merely a straightforward replication of movements, but rather a complex process of bioinformational processing, where perceptual and response information are continuously activated, feedback is provided, and optimizations occur. The Triple Code Model proposes that motor imagery is not solely a visual or bodily experience; instead, it is a multifaceted psychological activity that encompasses various components. This model defines motor imagery as comprising three forms of coding: Image, Somatic Response, and Meaning. However, Perry and Morris[7] note that, aside from the bioinformational theory related to emotional imagery, research has yet to rigorously explore the other theories. These theories have limitations in offering a comprehensive explanation of the mechanisms underlying motor imagery effects[20].

As Davids[1] points out, a thorough understanding of motor imagery and its modulating factors on performance effects must be grounded in appropriate interpretations of the psychological processes and theoretical mechanisms involved.

In addition to these theories, Grush's Emulation Theory of Representation[21] has gained increasing recognition in recent research. This theory posits that motor imagery is driven by a "simulator" controlled by the brain's central command center. This simulator mimics the execution of movements while bypassing the normal motor pathways that control muscle output. The simulator receives commands from the brain's control center and evaluates sensory experiences related to the movement, functioning similarly to the input and output roles of the brain's motor cortex.

During motor imagery, the control center sends commands to the simulator, which receives corresponding neural currents. Motor imagery training involves the repeated input of these neural currents. When a real movement is about to occur, the neural currents that have been trained through the simulator affect the motor cortex, thus controlling the muscles to execute and complete the action, as illustrated in Figure 2.

With advancements in electroencephalography (EEG) technology, studies have shown that motor imagery and actual movement engage similar brain regions, including the premotor cortex, supplementary motor area (SMA), basal ganglia, parietal cortex, and cerebellum[22,23]. Research by Ehrsson [24] has demonstrated that imagining movements of the fingers, tongue, and toes can systematically activate specific areas of the primary motor cortex. Additionally, findings from Li[25] indicate that motor imagery can also activate spinal motoneurons. These results suggest that motor imagery can, to some extent, reflect the cortical activity patterns of the brain.

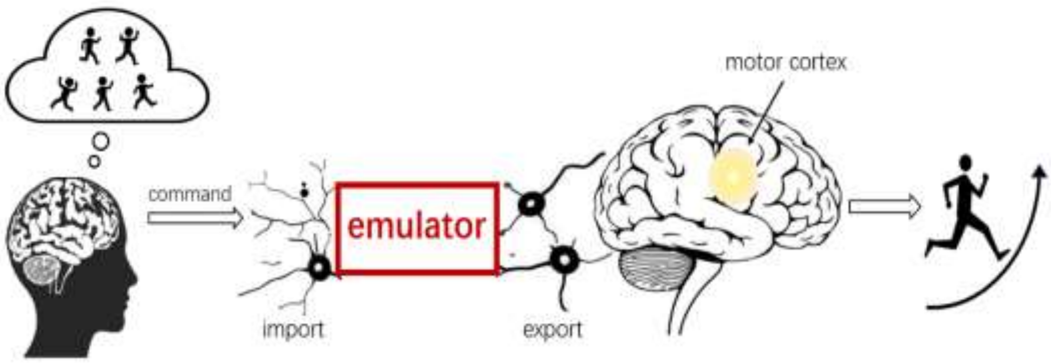

Figure 2 Diagram of the theoretical mechanism of representational simulation

1.2 Mechanistic study of action observation

When observing the actions of others, the same neural regions in the brain that are responsible for executing those actions become activated. This phenomenon is rooted in the mirror-neuron system (MNS)[26]. Mirror neurons were first identified in the cerebral cortex of macaque monkeys.

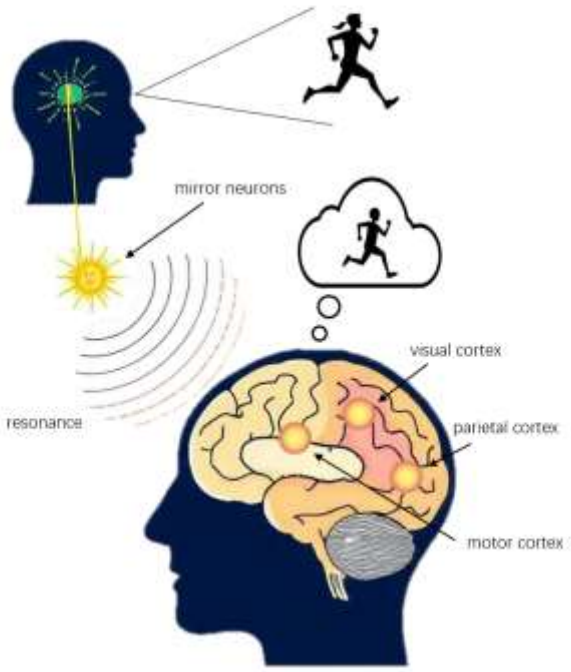

Figure 3 Action observation mechanism diagram

Research indicates that these neurons fire both when individuals execute goal-directed actions with various biological effectors and when they observe another person performing the same or similar actions[27–29]. In a study utilizing transcranial magnetic stimulation, Fadiga[30,31] was the first to demonstrate the presence of a mirror-neuron system in the human cerebral cortex. Action observation refers to the activation of specific brain regions associated with the mirror-neuron system through the observation of others' actions. When individuals witness someone else's actions, the specific brain regions corresponding to executing those actions are activated. These regions encompass neural pathways relevant to action execution. Mirror neurons transmit the observed motor signals to the motor system, creating a resonance phenomenon. This resonance facilitates motor pathways and influences the visual cortex, motor cortex, and parietal cortex, thereby enhancing the learning and mastery of motor skills, as illustrated in Figure 3.

In a functional magnetic resonance imaging (fMRI) study[32], researchers examined whether the presumed mirror-neuron system in humans could be activated by observing the actions of different species. The results indicated that regardless of the species observed, actions such as biting activated the premotor cortex and the inferior parietal lobule. However, the premotor cortex and the inferior frontal gyrus (Broca's area) were only effectively engaged when participants observed actions performed by members of the same species; observing communicative gestures made by monkeys or dogs did not produce the same effect.

These findings suggest that the presumed mirror-neuron system in humans can only align observed actions with the neural structures involved in executing them when those actions fall within the observer's motor repertoire. Furthermore, the observer's motor expertise influences the mirror-neuron system's recruitment. In another fMRI study, professional dancers who watched another dancer perform the same dance they had practiced experienced a stronger resonance effect compared to when they watched different types of dance. This supports the notion that an observer's motor expertise may lead to a distinct response within the mirror-neuron system. Additionally, some studies have demonstrated that the presumed mirror-neuron system in humans plays a role in imitation. In one fMRI study, participants were instructed to observe and imitate finger movements and then execute the same movements following spatial or symbolic cues[33] The results revealed two activated areas in the left inferior frontal cortex and the rostral region of the posterior parietal cortex, both of which are part of the mirror-neuron system. Broca's area has also been confirmed in other studies to be involved in goal-directed action imitation[34,35]. Recent data suggest that the mirror-neuron system also contributes to the finer cognitive aspects of action understanding, which can be enhanced through action observation.

1.3 Mechanistic study of AO+MI

After discussing the mechanisms of Action Observation (AO) and Motor Imagery (MI), we now focus on their combination: AO + MI. In examining the effects of AO + MI on behavior, we hypothesize that the neurocognitive components of AO and MI, when considered independently, remain largely intact during AO + MI, functioning either independently or coexisting and interacting in some manner. AO + MI may involve two parallel, separable motor simulation processes, a core theory referred to as "dual action simulation" (DAS)[36]. This theory is founded on behavioral research and a broader framework of biased competition[37].

Although the dual action simulation theory (DAS) has yet to be fully validated through empirical research, most related studies have concentrated on measuring the corticospinal excitability of the primary motor cortex (M1) using transcranial magnetic stimulation (TMS)[38]. Accordingly, Eaves et al. (2022) suggested employing tools such as multivoxel pattern analysis (MVPA) to further investigate these neural processes and elucidate the potential of dual action simulation. The additional benefits of AO + MI, in comparison to separate AO and MI, may be attributed to the distinct information sources provided by each simulation mode. These benefits do not necessarily stem from the interaction between the two but rather depend on the availability of the information required for specific learning tasks[39]. Research indicates that standalone AO uniquely provides an external visual reference, while standalone MI offers sub-threshold sensory references and physical feedback, enhancing participants' action learning capabilities (as illustrated in Figure 4A)[40,41], When AO and MI are combined, they enrich motor representation and enhance the benefits derived from both modes, thereby improving learning efficiency (as shown in Figure 4B). Moreover, during the process of motor learning, AO + MI training better equips learners to access the comprehensive information available during actual practice (PP) (as depicted in Figure 4C) [42,43]。

The learning advantages of AO + MI are not only evident in synchronous learning but also extend to asynchronous assisted learning.

Even when the dual action simulation processes are disrupted, asynchronous AO + MI can still yield additional learning benefits through continuous information provision[44]. Furthermore, introducing transfer designs to assess learners' abilities to apply skills across different tasks is crucial, although such designs remain relatively scarce in AO + MI research. Transfer testing can reveal learners' sensitivity to specific information and differentiate whether they have developed specific or non-specific representations. Compared to standalone AO or MI, AO + MI may facilitate better performance in transfer tasks.

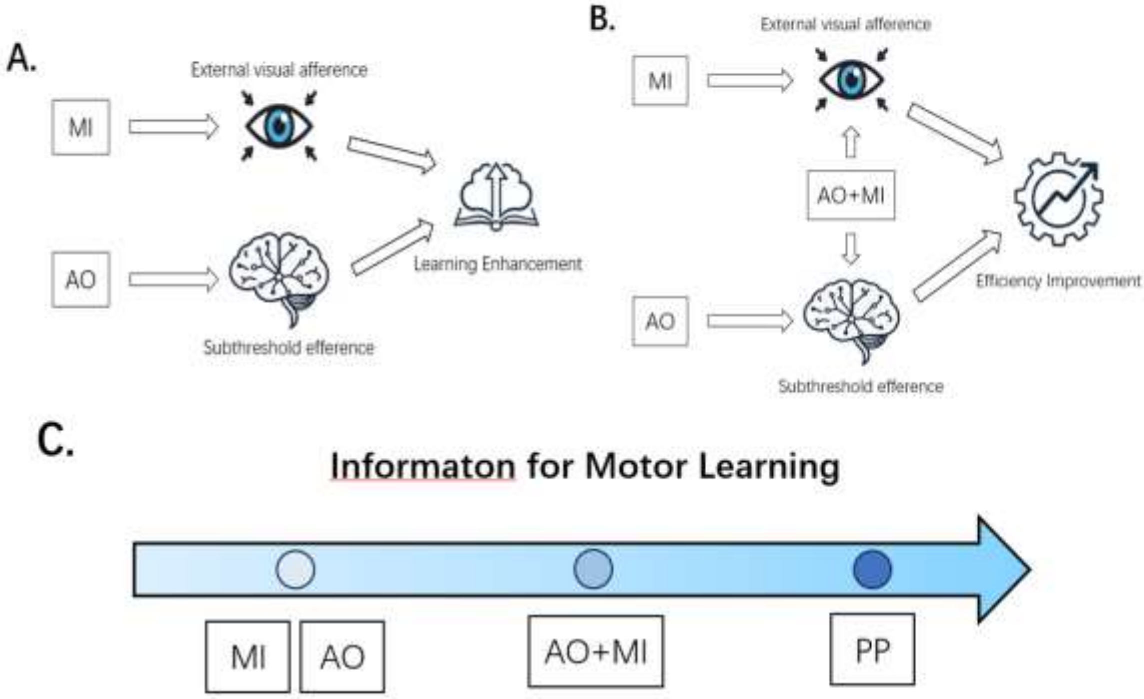

Figure 4 Dual action simulation theory

1.4 MI combines multiple states of AO

Despite the longstanding research on Action Observation (AO) and Motor Imagery (MI) as subforms of action representation or simulation[45,46], these studies have predominantly been conducted by different groups in isolation, resulting in a lack of comprehensive exploration of the concurrent operation of AO and MI. Previous research has typically focused on AO or MI individually; however, the composite state of AO and MI (i.e., AO + MI) has not been thoroughly examined.

As research has evolved, the mutual enhancement between AO and MI has gained attention, particularly through advancements in neuroimaging techniques. Researchers have found that AO + MI may activate a broader range of brain regions compared to AO or MI alone. This suggests that when individuals observe an action while simultaneously imagining themselves performing the same action, the neural activation patterns in the brain differ from those elicited by AO or MI performed separately. For instance, studies by Macuga[47] and Nedelko[48] indicate that neural activation during the AO + MI state is more robust than in the individual AO or MI states, highlighting the potential for these two representational processes to enhance each other when they occur concurrently mutually.

This article will explore three composite states of AO + MI: "concurrent AO + MI," "coordination between AO and MI," and "conflict generated by AO and MI," as illustrated in Figure 4.

1.4.1 Joint AO+MI

The composite state of Action Observation (AO) and Motor Imagery (MI) refers to the concurrent functioning of these two processes in the brain and the state that arises when both occur simultaneously. This phenomenon is characterized by "dual simulation," which describes a scenario in which an observer not only watches another person act but also imagines themselves executing a similar action. At first glance, this concurrent simulation might seem like an unnecessary repetition; however, in the context of inconsistent or conflicting AO + MI states, the "dual simulation" phenomenon can be critically important. In isolated AO, the observer primarily focuses on another person's actions, allowing for predictions of subsequent movements without directly involving their actions. When AO and MI occur simultaneously, the observer's body becomes "open," indicating that they are not merely observing but are also transforming the observed movements into bodily sensations (for instance, imagining their hand moving while watching hand motions) and even incorporating more subtle sensations in the simulation (such as the feeling of pressure from a toothbrush). This phenomenon suggests that the intensity of brain activation when processing AO + MI is significantly higher than during isolated AO, particularly in the somatosensory cortex [49–52]. While the activation of the somatosensory cortex has been demonstrated in MI research, it has not been adequately discussed in the context of MI studies.

One study indicates that participants' spontaneous engagement in MI during standard AO tasks may often be overlooked. In some experiments, although researchers only provided AO instructions, participants might spontaneously engage in MI. For instance, in a dance observation study[53], spectators were asked to assess the fatigue level of the dancers' movements. Such instructions may inadvertently trigger spontaneous AO + MI. This uncontrolled spontaneous behavior could potentially confound research results. Most existing AO studies have not thoroughly explored this self-generated phenomenon, even though research has shown that the activation patterns for AO and AO + MI differ. A study on mirror neurons suggests[28], that the temporal coupling between observed external actions and internal movement representations is very close; however, there is currently limited information on the coupling between MI-related simulation processes[54]. Some scholars argue that when AO + MI occurs simultaneously, it may occupy cognitive resources typically allocated for simulating observed actions, potentially impacting performance on prediction tasks. In some cases, this dual process might reduce predictive accuracy, while in others, it could enhance task performance.

1.4.2 Coordination between AO+MI

In situations where there is an inconsistency between Action Observation (AO) and Motor Imagery (MI), coordinating these two processes to facilitate joint actions becomes particularly crucial. Specifically, when an observer watches action B while imagining themselves performing a different action A—especially when there are no commonalities between the two actions (i.e., "conflicting AO + MI")—they may face challenges.

However, in everyday life, the observation and execution of different actions are more common than pure imitation, especially in joint actions like cooperation or competition. What constitutes a joint action[55]？ For instance, musical ensembles or competitive sports often necessitate the coordination of various movements. Although these movements may appear unrelated, participants can still harmonize them to achieve a shared goal. In a jazz ensemble, for example, the singer and the bassist synchronize their movements through precise timing[56]. This highlights that coordinating two actions amidst inconsistencies between AO and MI is a valuable skill and a reflection of joint action capability. Furthermore, the coordination process between AO and MI does not involve a complete replication of the observed actions; rather, it emphasizes specific aspects of the movements being observed[57], For instance, when observing a skier, the observer might focus on the knee movements rather than the overall action. Coordinated AO + MI enables flexible attention allocation, fostering adaptability in action simulation. This coordination process is not only prevalent in daily life but also has significant applications in sports training and rehabilitation.

1.4.3 Conflicts Arising from AO+MI

There not only exists a co-occurrence between Action Observation (AO) and Motor Imagery (MI), but there may also be instances of conflict between them. Although AO + MI is typically regarded as coordinated, in certain situations, they may indeed conflict with each other. Even though this phenomenon may seem rare or difficult to benefit from, conflicting action instructions or tasks frequently arise in psychology and neuroscience. Most existing studies[58] on the "automatic imitation effect" rely on contrasts between compatible and incompatible visual stimuli during action planning as a methodological tool. Eaves[59] investigates the potential for AO + MI conflict through experimental paradigms, where they observe participants' "imitation bias" responses by presenting different actions (such as brushing teeth and cleaning windows) while manipulating the rhythm of those actions. Imitation bias refers to the tendency of observers to unconsciously mimic the actions they observe. The results indicate that in cases of consistent AO + MI, this imitation bias is stronger, while in inconsistent AO + MI conditions, the bias is weaker, suggesting that the competitive strength between the two varies[60]。

In tasks involving joint AO + MI, participants simultaneously observe and imagine consistent actions. In the coordinated condition of AO + MI, the types of observed and imagined actions or planes of movement differ. In the conflicting AO + MI condition, participants observe static images while imagining dynamic, rhythmic actions. Through these manipulations, researchers can measure the strength of imitation bias under different conditions and gain further insights into the relationship between AO and MI[61,59].

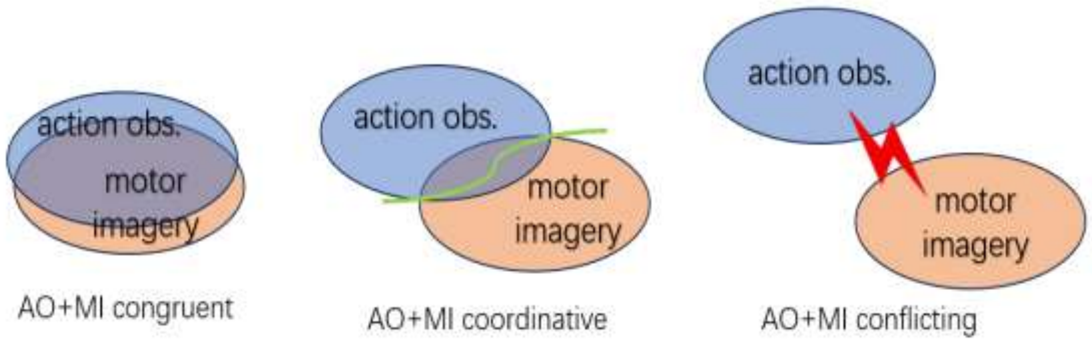

Figure 5 AO+MI three composite states

2 MI combined with AO in rehabilitation

2.1 Effects of AO+MI on corticospinal excitability

Corticospinal excitability (CE) refers to the activation state or responsiveness of neurons along the pathways that connect the cerebral cortex to the spinal cord. This process is primarily regulated by the motor cortex, which plans and executes movements, with signals transmitted through the spinal cord to target muscles. A decline in corticospinal excitability is associated with various neurological conditions, including Multiple Sclerosis (MS), Epilepsy, Cerebral Palsy, and Dystonia. Recent studies suggest that combining Action Observation (AO) with Motor Imagery (MI) can boost corticospinal excitability more effectively than either AO or MI alone.

In a study by Grilc[62], transcranial magnetic stimulation (TMS) was used to examine how lower-limb coordination during AO + MI affects corticospinal excitability. The findings revealed that changes in CE were driven by imagined actions during lower-limb coordination in AO + MI. Similarly, Moriuchi[63] conducted a study in which 16 participants performed a dual-hand piano-playing task involving AO + MI, with neurophysiological assessments conducted throughout. The results showed that corticospinal excitability was enhanced during AO + MI, especially in more complex MI tasks. Yasui[64] further investigated this by being the first to use peripheral nerve electrical stimulation (ES) in combination with AO + MI (referred to as AO + MI + ES) to explore the timing of CE changes. TMS was used to measure motor-evoked potentials (MEPs) in healthy individuals, revealing that AO + MI + ES induced cortical plasticity more rapidly than either AO + MI or ES alone. Additionally, individual imagery ability played a key role in the CE changes following AO + MI + ES. However, some researchers have proposed alternative perspectives. Kaneko[65] used a walking AO + MI task in a short-term intervention to examine the effects on corticospinal and spinal motor neuron excitability, as well as participants' MI ability. The results showed that while AO + MI intervention improved MI ability in healthy individuals, it was insufficient to produce changes at both the cortical and spinal levels, and its efficacy was unrelated to the participants' MI ability. A meta-analysis[66] found that compared to control and AO groups, AO + MI had a positive impact on MEP amplitude and motor outcomes, although it did not significantly affect MI. This suggests that AO + MI has a stable effect on motor-related outcomes. In addition to combining AO + MI with peripheral nerve electrical stimulation, recent studies have explored its integration with virtual reality (VR) technology.

VR-based AO provides immersive visual information that can enhance MI by fostering a sense of embodiment, allowing individuals to perceive themselves as part of the observed action. For instance, Lakshminarayanan[67] hypothesized that using VR to create immersive visual scenes during AO could enhance cortical activity associated with MI. The results indicated that VR-based AO + MI enhances motor imagery abilities and stimulates related cortical areas. Similarly, Connelly[68] used VR action observation combined with MI (VR-AO + MI) to evaluate whether it could enhance neuroplasticity in the motor cortex of healthy adults and to identify predictors of neuroplastic changes following VR-AO + MI. The study found that participating in VR-AO + MI enhanced neuroplasticity and could potentially stimulate the brain to further increase neuroplasticity within this group.

2.2 Effectiveness of AO+MI in Developmental Coordination Disorder

Developmental Coordination Disorder (DCD) is a neurodevelopmental disorder marked by significantly below-age-level motor skill development in children, adversely affecting their ability to perform daily activities and learn new motor skills. DCD is typically diagnosed during childhood and often coexists with other learning disorders or Attention Deficit Hyperactivity Disorder (ADHD). It is believed to stem from functional abnormalities in brain regions responsible for motor planning and execution. Recent interventions combining Action Observation (AO) and Motor Imagery (MI) have shown promise in addressing DCD.

In a study conducted by Marshall[69], the effects of AO + MI intervention were examined to determine whether it alleviates deficits in internal models and enhances hand-eye coordination during visual-motor rotation tasks. The AO + MI group outperformed the control group, demonstrating faster completion times, more focused eye movements toward targets, and smoother motor execution. This study suggests that AO + MI interventions can help mitigate these deficits and improve motor performance in children with DCD. Scott has made substantial contributions to this field through several studies. One study[70] found that children with DCD exhibit deficits in both imitation and MI compared to typically developing peers. By integrating AO with MI instructions, imitation abilities can be enhanced. The study involved three modules: (1) observing the target action before imitation, (2) observing and then imagining the action before imitation, and (3) simultaneously imagining the same action while observing before imitation. Analysis revealed that AO + MI significantly improved imitation performance compared to the other two instruction types. Notably, the DCD group showed a marked advantage with AO + MI over simply observing and then imagining. Among typically developing children, the AO + MI group exhibited significant enhancement in imitation relative to those who observed first and then imitated. In another study[71], the impact of combining action observation and motor imagery on automatic imitation in children aged 7-12 years was assessed. The results indicated that the combined effect of AO + MI in typically developing children was significantly greater than that of AO alone. Both children with and without DCD demonstrated substantial capabilities in various forms of motor imitation, with the AO + MI combination proving to be an effective training method for children with diverse motor abilities. A third study[72], investigated the efficacy of a family-based, parent-led AO + MI intervention in helping DCD children learn Activities of Daily Living (ADL).

The findings suggested that such an intervention could facilitate DCD children's acquisition of complex ADLs and may be particularly effective in promoting the development of motor skills currently absent from their repertoire.

2.3 Rehabilitation effects of AO+MI in stroke patients

Stroke, also referred to as cerebrovascular accident (CVA) or brain stroke, is an acute cerebrovascular event characterized by damage to brain tissue resulting from either blood flow obstruction or the rupture of blood vessels. Strokes are generally classified into two primary categories: ischemic stroke and hemorrhagic stroke, with ischemic stroke being the most prevalent, accounting for approximately 80% of all cases. Strokes often lead to severe consequences, including motor function impairment, speech difficulties, and cognitive decline. Research has indicated that Action Observation (AO) and Motor Imagery (MI) can significantly impact both language and cognitive functions.

Emerson[73] concentrated on motor system impairment and the recovery of motor skills. His assessment of action observation therapy (AO) and motor imagery training (MI) led to the recommendation of these techniques for post-stroke rehabilitation. He proposed that the combination of AO and MI (AO + MI) might represent a more effective approach, suggesting that this integrated method outperforms the individual practices of AO and MI. Binks[74] investigated the effects of AO + MI therapy on upper limb recovery in chronic stroke patients. In a study involving increasingly complex cup stacking tasks, he compared four types of mental practices (AO + MI, AO, MI, and Control). The results revealed that the AO + MI combination significantly reduced movement execution time compared to both MI and Control groups. Participants also reported notable improvements in their quality of life and positive experiences associated with AO + MI. The study concluded that when physical exercise is not suitable, the AO + MI combined therapy could serve as an effective adjunct in the neurorehabilitation of chronic stroke survivors. However, while AO + MI has a positive effect on upper limb recovery, its efficacy for lower limbs may be less pronounced. Behrendt[75] examined whether lower limb reflex responses are modulated during walking with combined AO + MI, measuring the median latency of the tibialis anterior muscle's skin reflex. The findings indicated that even using methods similar to those in studies with healthy individuals, no significant modulation of reflex responses was observed. MI and AO are commonly employed in stroke rehabilitation practices involving brain-computer interfaces (BCI). Previous studies have reported that the combination of AO and MI (AOMI) is more effective than either MI or AO alone in enhancing event-related desynchronization (ERD), which reflects cortical excitability and improves classification performance in BCI systems for healthy subjects. Rungsirisilp[76] explored the effects of AOMI on ERD and classification performance in chronic stroke patients. The results showed that ERD values and classification accuracy in the AOMI condition were significantly higher than those observed under MI conditions. A significant negative correlation was found between ERD values and classification performance, suggesting that enhanced ERD values (more negative values) correspond to improved classification performance.

3 Conclusions

1、Motor Imagery (MI) and Action Observation (AO) activate neural networks associated with motor control in the brain, demonstrating a significant overlap with the neural networks involved in actual motor execution. Traditional theoretical frameworks suggest that MI operates through a concept of a brain "simulator," while AO is supported by mirror neuron theory, in which "mirror neurons" play a pivotal role. These theories highlight substantial similarities between MI and AO.

2、The combined intervention training method of AO and MI has gained increasing attention in research. The theoretical mechanism underlying AO + MI is known as the dual-action simulation (DAS) mechanism, which posits that integrating AO and MI enhances external visual input, provides sub-threshold sensory references, and delivers physical feedback, ultimately improving learning efficiency and practical performance. However, the integration of AO and MI may occur simultaneously, in coordination, or even in opposition, requiring careful consideration of the specific context.

3、Current research has established that the combined practice of MI and AO offers positive benefits for cognitive rehabilitation patients. Studies investigating cortical excitability (CE) generally indicate that AO + MI activates CE. Nonetheless, there remains considerable debate about whether AO + MI training genuinely leads to positive effects on CE activation. Research involving patients with developmental coordination disorders and stroke survivors suggests that AO + MI can enhance motor functions of both upper and lower limbs, improve event-related desynchronization (ERD) capabilities, and boost activities of daily living.

4 Future outlook

In the study of Motor Imagery (MI), Action Observation (AO), and the combined approach of AO + MI, numerous theories and hypotheses have been proposed to explain their underlying neural and cognitive mechanisms. Among these, MI has the broadest range of theoretical interpretations; however, no single theory has gained universal acceptance among scholars. As research in this field continues to progress, further discoveries are anticipated that may lead to more effective, evidence-based methods for applications such as cognitive rehabilitation.

This article primarily explores the impact of AO + MI on cognitive rehabilitation. However, in reviewing the literature, we also found instances of AO + MI being combined with peripheral nerve electrical stimulation (ES) and with virtual reality (VR) technology, resulting in an intervention known as (VR-AO + MI). Notably, two studies utilizing (VR-AO + MI) as an intervention method reported promising results. Future research may investigate the potential of combining AO + MI with additional intervention strategies to determine whether a multimodal approach could yield enhanced outcomes.

While the application of AO + MI in cognitive rehabilitation has shown positive results, not all studies report favorable effects. Some research has raised doubts about the efficacy of AO + MI in modulating corticospinal excitability. Additionally, certain scholars suggest that AO + MI may not always lead to better outcomes; in some cases, it might produce results similar to or even less effective than standalone AO or MI, with a risk of interference effects that diminish the intervention's efficacy. Future experiments using AO + MI should carefully consider and control for potential confounding factors to maximize its therapeutic impact.

Disclosure

Author's contribution

Conceptualization: Zhang Mufan; Methodology: Zhang Mufan; Check: Luo Jiong; Writing - review and editing: Zhang Mufan; Project administration: Luo Jiong; Receiving funding - no specific funding.

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