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Review

Effects of Motor Imagery Combined With Action Observation on Motor Function in Stroke Patients

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Abstract

Stroke symptoms encompass sensory, cognitive, motor, and psychosocial dysfunctions, with motor impairment being the most prevalent. This impairment significantly contributes to functional incapacity and a diminished quality of life. Stroke rehabilitation strategies primarily aim to promote neural reorganization and motor skill recovery. Among these, motor imagery (MI) and action observation (AO) are distinct therapeutic techniques with unique mechanisms of action. This review begins by analyzing the strengths and limitations of each approach individually and argues that integrating MI and AO therapy could offer a more effective rehabilitation strategy. A thorough evaluation of relevant literature is presented, detailing methodologies, key findings, and implications. The objective is to elucidate the potential benefits and underlying mechanisms of combining these two therapies in stroke rehabilitation. In conclusion, the article advocates for the adoption of combined MI and AO therapy in neurorehabilitation.

Keywords: motor imagery; action observation; motor function; stroke rehabilitation

1. Introduction

Stroke is a leading cause of disability and mortality worldwide, resulting from significant brain infarction or hemorrhage [1]. Global data reveal two primary types of stroke: ischemic and hemorrhagic. Ischemic stroke, accounting for approximately 80% of cases, often leads to a spectrum of motor impairments. These include hemiparesis (weakness on one side, limiting tasks such as lifting an arm or leg), spasticity (increased muscle tone and stiffness, particularly in the arms and legs), coordination and balance issues (e.g., gait difficulties), and sensory deficits (reduced limb sensation), all of which severely impact daily functioning [2,3]. The primary goal of stroke rehabilitation is to improve the patient's ability to move and grasp objects effectively [4]. While traditional rehabilitation methods such as physical therapy (PT) and exercise remain foundational, advancements in neurorehabilitation have spurred the exploration of innovative interventions aimed at promoting neuronal reorganization and restoring motor function [5].

Motor imagery (MI) is a cognitive process in which individuals mentally simulate or rehearse a movement without physically executing it [6]. In stroke rehabilitation, MI has been investigated as a complementary approach to promote motor function recovery [7]. A study by Kobelt *et al.* [8] demonstrated that during hand-grasping and arm-lifting exercises, seven participants (including two healthy volunteers, three stroke patients, and two patients with Parkinson's disease) exhibited electromyography (EMG) activation in at least one target muscle during MI. Interestingly, no consistent relationship was found between MI ability assessments and EMG activation during MI. This suggests that MI may induce subconscious EMG activation, which varies among individuals. However, the factors influencing EMG activation during MI remain unclear [8]. This modality has been particularly explored among chronic stroke survivors with paretic upper limbs [9,10]. Action observation (AO), on the other hand, is a multi-sensory approach that involves observing another individual performing a motor task, followed by the imitation of the observed action. AO can include viewing actions performed by a healthy person on a screen [11] or observing them physically in face-to-face interactions [12]. AO has been shown to enhance cortical excitability in the primary motor cortex (M1) [4]. Additionally, a study indicates that AO activates brain regions such as the parietal lobe and premotor cortex, which are similarly engaged when performing the observed action, thereby supporting movement recovery in stroke patients [13]. For example, Fawcett and Liszkowski [14] conducted a study with 48 infants aged 18 months to explore object demonstrations under three conditions: joint action by two models, individual action by two models, and solitary action by one model. The results revealed that 18-month-old infants observing joint actions were able to encode both individual object-directed goals and joint social goals [14].

MI and AO are distinct neurorehabilitative techniques that have demonstrated the potential to improve motor function in stroke patients [15,16]. Extensive research highlights their ability to enhance motor function across various contexts in stroke rehabilitation [17–19]. These techniques contribute to reactivating motor pathways, refining precision, improving reaction times, and facilitating movement planning. Beyond stroke, MI and AO are also employed in managing neurodegenerative diseases, such as Parkinson's disease, to maintain functional mobility and mitigate motor decline [20,21]. The combination of MI and AO offers an integrated approach to motor skill acquisition, neuroplasticity, and recovery. This dual strategy addresses individual differences in cognitive processing, motor abilities, and learning preferences, providing a comprehensive and holistic framework for motor rehabilitation [22,23]. MI and AO are user-friendly, cost-effective, and safe, requiring minimal supervision and no specialized or expensive equipment. Despite their advantages, most studies have investigated MI and AO techniques in isolation for upper and lower limb rehabilitation following stroke [24–28]. These studies do not consistently indicate superior outcomes in motor function or activities of daily living (ADL) compared with conventional rehabilitation therapies such as PT and occupational therapy (OT).

Despite encouraging findings, evidence directly comparing the combined effects of MI and AO with each technique used in isolation remains limited. While the individual benefits of MI and AO are well-documented, their synergistic potential, particularly in stroke rehabilitation, is still underexplored [29,30]. Existing research reveals variability in outcomes, with some meta-analyses reporting only small to medium effects of combined MI and AO on motor recovery [31]. These inconsistencies highlight the need for robust, standardized studies to investigate critical factors influencing effectiveness, including timing, intensity, and sequencing of interventions. Furthermore, few studies systematically address how patient-specific variables, such as stroke severity, cognitive function, or imagery ability, impact the efficacy of combined MI and AO. This knowledge gap limits the potential for personalized treatment approaches tailored to optimize recovery outcomes [32,33]. Additionally, research has predominantly focused on short-term outcomes, with limited exploration of the long-term retention of motor improvements achieved through combined MI and AO therapy [20,34–36]. Understanding the sustainability of these benefits is essential for designing comprehensive and effective rehabilitation programs. To support evidence-based clinical decision-making, this review will summarize recent research on the therapeutic potential of combining MI and AO. The goal is to evaluate whether integrating these two approaches can enhance motor recovery and improve outcomes for stroke patients.

2. Methodology

The methodology of this study involved conducting online literature searches across multiple electronic databases, including PubMed, Web of Science, the Cochrane Library, Embase, Google Scholar, Scopus, and CNKI, to identify English-language studies. Relevant articles were also reviewed to ensure comprehensive coverage. The search strategy was developed using subject headings related to stroke, including ischemic stroke, hemorrhagic stroke, MI, AO, and combined MI with AO in rehabilitation.

3. Effects of MI on Motor Function in Stroke Patients

Motor function refers to the ability to control and coordinate muscle movements. Stroke-induced motor dysfunction remains a significant challenge for patients, underscoring the importance of rehabilitation techniques such as MI. The neuroimaging study has demonstrated that MI activates brain regions involved in actual motor execution, including the M1, premotor cortex, and supplementary motor area, which are responsible for coordinating motor tasks. These regions interact with the cerebellum and basal ganglia, which contribute to motor control, error correction, and communication with pathways such as the corticospinal tract, which transmits motor commands to the spinal cord [37]. A randomized controlled trial (RCT) by Li *et al*. [38] revealed that 4 weeks of MI training combined with traditional rehabilitation significantly improved hand function in stroke patients, likely through the enhancement of dorsal pathways. The middle temporal area (MT/V5) was implicated in conveying sensory information crucial for motion planning and control, supporting motor execution [38]. Additionally, neurotransmitters such as acetylcholine and dopamine play essential roles during MI. Acetylcholine is associated with synaptic plasticity, which is critical for attention and motivation, while dopamine modulates attention and reinforces neural pathways, consolidating learning and facilitating post-stroke motor recovery [39].

A survey conducted with individuals experiencing hemiparesis suggested that 6 weeks of home-based MI treatment improved walking speed on the affected side and significantly enhanced step and foot rhythm [40]. These improvements may be attributed to the patients' focused engagement during imagery practice. Previous meta-analyses of RCTs have also shown that MI can enhance walking ability and overall motor function in stroke patients [9]. This success is largely attributed to patients' adherence to MI training protocols, which promotes increased use of the affected limb following intervention. MI therapy may help overcome limb nonuse by either modifying the existing motor framework responsible for neglecting the more affected limb or creating a new motor framework that incorporates its use [41].

While MI alone can enhance motor function in stroke patients, several studies have shown that combining MI with PT or other standard rehabilitation methods yields better outcomes [42,43]. MI does not need to replace physical exercise; rather, it can complement traditional rehabilitation techniques such as PT and OT. In a study involving 40 post-stroke individuals, participants were divided into two groups: the experimental group engaged in MI alongside structured progressive circuit class therapy, while the control group participated in health education with structured progressive circuit class therapy three times a week for 4 weeks. Significant endurance, balance, and functional mobility improvements were observed across several outcome measures. These gains were particularly evident in the step test, where a metronome was used to guide the stepping rhythm, resulting in notable improvements in stepping with the affected limb.

Recent evidence suggests that combining MI with traditional neurorehabilitation methods, such as PT, OT, mirror therapy, and constraint-induced movement therapy, results in significant improvement in motor performance, particularly in the lower limbs of stroke patients. While movement-related measurement tools, including the Berg Balance Scale, Functional Independence Measure, and Fugl-Meyer Assessment-lower extremity (FMA-LE), are not therapeutic techniques themselves, they play a critical role in outcome-based stroke rehabilitation [25]. These scales assess balance (Berg Balance Scale), functional independence (Functional Independence Measure), and lower extremity motor function (FMA-LE), enabling clinicians to identify specific targets for intervention, customize rehabilitation plans, and monitor progress over weeks to months [44]. This targeted approach improves mobility outcomes by addressing each patient's functional deficits and enhancing their quality of life. Moreover, evaluating the patient's MI skills before beginning treatment is essential for tailoring the rehabilitation process. In a similar study, an MI protocol incorporating lower extremity mobility tasks helped stroke patients to regain the ability to sit, stand, and use their knee extensors regularly. These findings underscore the potential of neurorehabilitative treatments to facilitate neuromotor recovery, reduce long-term disability, and alleviate the financial burden on the community [45].

MI involves guiding the participant to form vivid and accurate mental representations of movement, thereby activating motor-related brain regions and promoting recovery. As such, MI complements conventional rehabilitation approaches, especially when paired with advanced techniques such as brain-computer interface (BCI) technology. BCI adaptation significantly enhances stroke rehabilitation by promoting neurofeedback and facilitating interactions with brain-controlled devices. This interaction stimulates motor neurons, supports neuroplasticity, and aids in neural reconstruction through flexible variations. BCIs enable patients to perform tasks using only brain activity, often manipulating external systems such as robotic arms or virtual environments. This capability is particularly beneficial for stroke patients with severe motor deficits who are unable to perform voluntary movements, as it provides alternative pathways to activate motor circuits, helping to preserve and even restore neural connections in damaged regions [46]. Cervical BCIs offer real-time feedback, reinforcing motor intent and motivating patients by allowing them to experience movement sensations, even if they are not physically performing the action [47]. BCI systems, frequently combined with MI, convert brain signals into control commands or feedback, enabling stroke patients to receive immediate responses from their bodies and control external devices such as robotic limbs or virtual environments. This closed-loop feedback enhances the effects of MI by reinforcing neural pathways through neuroplasticity. The rehabilitation process becomes adaptive and precise, with movement parameters being adjusted based on trial outputs, facilitating rapid motor recovery and improving functional independence [48]. However, a recent RCT on BCI-MI in patients with severely compromised upper limb function in the subacute phase of stroke reported inconclusive results [49]. The lack of upper limb recovery in a significant portion of patients.

Graded MI (GMI) is a therapeutic approach that has gained increasing recognition in stroke rehabilitation. It consists of three stages: laterality recognition, imagined movements, and mirror therapy. The primary goal of GMI is to rewire the brain's sensorimotor networks, promoting motor recovery after a stroke. In a study by Ji *et al*. (2021) [26], GMI was shown to be effective in enhancing upper limb function and alleviating pain in stroke survivors. The researchers attributed these positive outcomes to GMI's ability to engage neuroplasticity mechanisms, driving adaptive changes in the brain. They proposed that GMI facilitates the reorganization of cortical networks responsible for motor control and pain processing, thereby improving upper limb function and reducing pain in stroke survivors. Additionally, the study highlighted the significance of active patient participation and consistent adherence to the GMI protocol as key factors contributing to the observed improvements [26].

MI and virtual reality (VR) have emerged as promising approaches in stroke rehabilitation. VR provides an immersive environment where patients can interact with simulated tasks, boosting engagement and motivation. It enables individuals to actively perceive their bodies in a simulated, ecologically valid, and safe environment, offering reality-like experiences [50]. Combining MI with VR allows patients to practice movements in a virtual environment, facilitating motor learning and promoting neuroplasticity. VR-based interventions can be tailored to the specific needs and preferences of each patient, providing personalized rehabilitation experiences. Overall, the integration of MI with VR holds great potential for optimizing stroke rehabilitation outcomes. A recent study demonstrated improvements in motor function performance attributed to the synergistic effects of VR immersion and mental rehearsal through MI. The success of this approach is rooted in its ability to provide personalized, intensive rehabilitation activities such as basketball shooting drills, allowing patients to actively engage in therapy and stimulate their motor cortex while leveraging neuroplasticity for enhanced recovery [51]. Im *et al*. [52] found significant increases in cortical excitability among both stroke patients and healthy volunteers through MI combined with VR training. The study involved 15 stroke patients and 15 healthy volunteers, randomly assigned one of four interventions: rest, MI alone, VR-guided MI, and VR-guided MI with task variability. Cortical excitability was measured before, during, and after the interventions. The results showed that the corticomotor excitability elicited by MI using VR was greater than that observed with real-body techniques. Additionally, task variability in the VR program appeared to enhance neural regeneration after a stroke by reducing intracortical inhibition [52]. This combined approach has the potential to improve motor function, balance, and activities of daily living in stroke survivors.

MI aids in facilitating movement patterns as well as employing facilitatory and inhibitory techniques, reflex-inhibitory patterns, higher-level reflexes, and muscle-tone regulation. MI is effective both as a standalone therapy and when combined with other rehabilitative approaches. It can significantly enhance motor function recovery after a stroke, benefiting patients in both the acute and convalescent phases of rehabilitation.

4. Effects of AO on Motor Function in Stroke Patients

Unlike MI therapy, AO involves both visual and executed movement. A previous study in the macaque monkey brain have identified "mirror neurons" and the mirror-neural system (MNS), which activate both when performing a motor action and when observing someone else perform a similar action [53]. The MNS comprises a network of brain regions primarily located in the frontal and parietal lobes. Key components of the MNS include the premotor cortex, supplementary motor area, inferior parietal lobule, and superior temporal sulcus. These regions collaborate to facilitate the understanding, imitation of observed actions, and processing of emotional cues and intentions of others [54]. Human studies have demonstrated similar properties of the MNS, which plays a crucial role in action comprehension [55], imitation [56], motor learning [43], and social interaction. The MNS can modulate training effects in healthy individuals and has been suggested to improve motor rehabilitation outcomes following a stroke by engaging the motor execution network [30]. The MNS, primarily located in and around the premotor cortex and inferior parietal lobule, activates similarly to performing the observed action, allowing the brain to "simulate" others' movements. This simulation is integral to understanding and imitating actions, which are essential components of motor learning [55]. Additionally, the MNS interacts with the motor cortex, preparing it for action. This interaction, in conjunction with limbic regions that process emotions linked to social and goal-directed behaviors, facilitates motor learning by providing a neural template for executing observed actions [57]. This process induces neuroplasticity, aiding in the relearning of lost skills in individuals with motor impairments through observation therapy [58]. The integration of the MNS with multimodal sensory inputs enhances its potential, enabling a synchronized connection between the motor and sensory systems. In AO and motor learning, visual and tactile modalities are essential: touch provides proprioceptive feedback, while sight supplies external action cues. This sensory-motor integration improves the brain's ability to encode, simulate, and learn motor tasks, stimulating larger neural networks such as the somatosensory and premotor cortices. By strengthening neuroplasticity, this multimodal coordination promotes more effective motor recovery and learning.

A study examined the effects of AO and exercise on individuals with persistent chronic ischemic strokes near the middle cerebral artery. Compared with a control group receiving only physical practice, the intervention group showed significant improvements in motor function, as measured by the Fugl-Meyer Assessment and the Action Research Arm Test. These improvements were notably sustained after a 2-month follow-up [22]. Another study investigated the effects of AO training using video clips in subacute stroke patients. The intervention group demonstrated improvements in upper limb motor function, as assessed by the Box and Block Test and the Motor Activity Log, compared with a control group receiving conventional therapy [59]. However, the use of video clips in this context has several limitations and potential biases. Video clips lack personalization, which can limit engagement and the effectiveness of motor learning. If the observed actions do not match the patient's functional level, they may not activate the MNS, which is a crucial mechanism in AO-based learning [60]. Additionally, the single perspective and absence of depth cues in video clips can hinder viewers' understanding of three-dimensional movement, which is important for motor learning. The lack of adjustable viewpoints further diminishes their effectiveness in facilitating action learning [61]. Observer biases, such as assumptions about movement difficulty or motor abilities, may influence how a video stimulates motor networks, potentially impacting self-efficacy, perceived relevance, and the overall benefits of motor learning [62]. Moreover, video-based neurorehabilitation may have limitations in terms of generalization and transferability. Idealized movements in the videos might not reflect the variations seen in daily activities, limiting their practical application in real-life settings [63]. Pre-recorded videos may also not align with user preferences, thereby affecting the learning experience. Timing plays a crucial role in AO, as faster or slower movements may not optimally engage motor-related brain regions [64]. Therefore, given these limitations and biases, therapists should consider alternative approaches, such as using real-time demonstrations by an actual person during AO, rather than relying solely on video clips.

To enhance dexterity recovery in subacute stroke patients with moderate to severe upper limb paresis, a study integrated AO with the direct effects of action execution. The study suggested that observing actions being executed can activate neuronal areas physiologically involved in action execution [65]. These findings align with earlier research [66,67], indicating that observing and imitating actions can enhance the excitability of motor regions in the brain, including the parietal lobe and primary motor cortex. This phenomenon is believed to facilitate the recovery of motor function and control in stroke patients. A recent study proposed that adopting multiple perspectives could offer advantages in various motor skill tasks. For example, a first-person viewpoint may be particularly beneficial for instructing complex manual dexterity activities such as grasping, gripping, and pinching different objects. This perspective helps integrate movement and provides essential visual cues for efficiently completing activities. In contrast, a third-person perspective might be more suitable for larger-scale gross motor tasks [68]. Another investigation highlighted the close relationship between observation perspective and brain activity during AO training. Observing from a first-person viewpoint elicits brain responses similar to those observed during actual movement [69]. Conversely, adopting a third-person perspective leads to brain responses resembling those triggered when observing another individual's action. It is important to recognize that both perspectives serve distinct situational contexts, each contributing differently to rehabilitation outcomes and goals. Further studies have emphasized the significant impact of observing repetitive actions on memory formation in the brain, suggesting potential benefits for ongoing motor learning and improvements in balance and gait abilities [28,70–72]. Notably, additional research has shown substantial enhancements in measures such as the dynamic gait index (DGI), 10-meter walk test (10 m WT), timed up-and-go (TUG) duration, and sit-to-walk performance [28,72]. These findings indicate that continuous observation of repetitive actions contributes to the development of the MNS, underscoring the potential effect of AO in stroke rehabilitation, particularly for improving lower limb motor functions.

Through VR-based AO, stroke survivors can enhance rehabilitation outcomes, neuroplasticity, and motor function. This approach fosters patient motivation and adherence to rehabilitation protocols, providing personalized, immersive therapy experiences tailored to individual needs. As such, it represents a promising strategy for stroke recovery. An RCT study by Errante *et al*. [73] found that combining AO therapy with VR led to increased motor facilitation and improved upper limb control and function, with benefits sustained over a 6-month follow-up period. The study employed a goal-oriented approach, aligning each patient's upper limb impairment level with exercises customized to their specific needs [73].

AO therapy shows promise in enhancing both upper and lower limb capabilities following a stroke, whether used alone or in conjunction with other treatment modalities. The positive outcomes observed, including improvements in gait, balance, and motor function of both upper and lower limbs, underscore the potential of this approach within neurorehabilitation paradigms. Further research in this area is crucial for optimizing stroke recovery interventions. By harnessing the power of observational learning and incorporating various perspectives, therapists can tailor interventions to specific motor tasks, thereby enhancing the rehabilitation process for stroke survivors. This multidisciplinary approach has significant implications for improving rehabilitation protocols and deepening our understanding of the underlying neurophysiological mechanisms.

5. Effects of MI Combined With AO on Motor Function Rehabilitation in Stroke Patients

Combining MI with AO in stroke patients leverages a unique set of neurophysiological mechanisms that synergistically enhance motor function recovery. Stroke patients who engage in both MI and AO simultaneously may experience amplified activity in the MNS, promoting increased neural plasticity. This heightened plasticity can lead to a more robust reorganization of motor-related neural circuits, facilitating motor recovery. Furthermore, the concurrent engagement of motor planning and execution regions during combined MI and AO contributes to an intensified motor rehabilitation effect [22]. These mechanisms collectively explain the observed improvements in motor function among stroke patients undergoing this combined therapy [42]. The functional neuroimaging study provides empirical support for the neural mechanisms underlying the combination of MI with AO [60]. Using techniques such as functional magnetic resonance imaging (fMRI), this study has shown that the simultaneous activation of MI and AO engages motor-related brain regions, including the premotor cortex, supplementary motor area, and cerebellum [60]. These regions are essential for motor planning, execution, and coordination. Moreover, the increased activity in the MNS resulting from the combined therapy further enhances the neural plasticity of these regions, leading to a more effective motor recovery [74]. Therefore, the neurophysiological mechanisms of combining MI and AO in stroke patients involve enhanced MNS activation, increased neural plasticity, and the simultaneous engagement of motor planning and execution regions, ultimately yielding superior motor function rehabilitation outcomes.

Sun and colleagues [23] examined 10 right-handed individuals who experienced left hemisphere-related disability due to stroke. These participants underwent a 4-week regimen involving both cognitive therapy and PT. Half of the participants concurrently engaged in MI of the same actions while simultaneously observing the actions for five rounds during the intervention. Specifically, the patients were asked to imagine lifting their right hand, grasping and inserting pegs into a hole, and removing them. The observation was primarily intended to provide visual guidance to support the concurrent MI action. In contrast the control group engaged in MI and AO in a serial, rather than combined, sequence. Remarkably, by the end of the 4 weeks, both the combined MI and AO therapy group and the control group exhibited improvements in their FMA scores, reaching clinically significant levels. This difference suggests that the combination of MI and AO therapy was effective in enhancing motor function, though it is important to consider that the observed improvements were not solely attributed to the sequence of therapy. The results suggest that both MI and AO therapy can effectively enhance upper extremity motor function in individuals recovering from a stroke. The study also proposed a novel perspective on the sequence of AO followed by MI. The authors noted that the mechanism by which mirror therapy successfully restores sensory-motor function involves the induction of plastic changes in motor areas of the brain through covert synchronous action MI combined with AO [23]. However, a deeper understanding of these effects will require further research.

Chye *et al.* [29] found that the movement meta-analysis supports the validity of combining MI and AO as a viable alternative to using either technique alone. However, they did not provide evidence that the concurrent use of MI and AO yields additive benefits over MI alone in improving motor performance [29]. The analysis revealed only small to medium effect sizes in favor of the combined approach. Nonetheless, even modest gains in motor function can be clinically significant and relevant in both neurorehabilitation and sports contexts [31]. Combining MI and AO offers a potential advantage by mitigating the individual limitations of each technique when used independently. For example, imagery ability—the capacity to create and regulate mental images—varies greatly among individuals and some people may struggle to generate vivid or strong images during MI [32]. Conversely, AO interventions, where movements are demonstrated through video, are less reliant on individual imagery ability [27]. However, the success of AO depends on the observer's ability to focus on critical components of the demonstrated movement [75]. According to recent guidelines for implementing MI combined with AO, this approach regulates the visual data presented through AO while directing attention to the kinesthetic aspects of movement. This strategy simplifies the mental demands of MI, reducing cognitive load during rehabilitation while optimizing motor recovery by balancing sensory and motor processes [33]. Consequently, combining MI and AO is an effective method for enhancing neuroplasticity and motor learning in stroke rehabilitation programs.

Previous studies have provided robust evidence supporting the effectiveness of combining MI with AO to facilitate the acquisition of complex motor skills, even in the absence of hands-on practice [76,77]. These findings align with research conducted in neurotypical populations, demonstrating the superiority of MI and AO training over either technique used in isolation. A key strength of this study lies in its meticulous research design, which fully counterbalances potential sources of variability, offering valuable insights into motor learning through mental practice in stroke survivors [78]. One intriguing result was observed during the 2-week retention test, where the main effect of the practice condition became more pronounced compared with the immediate post-test [79]. This outcome complements earlier research by underscoring the efficacy of the combined MI and AO approach in enhancing neurorehabilitation, particularly for upper-extremity recovery among stroke survivors [23,80,81]. Notably, the study achieved significant improvements in a relatively short training duration, with these benefits persisting over the 2-week retention period. The synchronous application of MI and AO therapy contributed to marked enhancements in upper-extremity motor function and cortico-motor activation [35]. These findings are consistent with prior research showing improvements in FMA scores and increased corticospinal excitability in stroke survivors. Furthermore, by assessing motor performance during the retention period, this study extends the foundational evidence provided by previous researchers, reinforcing the long-term benefits of combining MI and AO in stroke rehabilitation.

Aoyama *et al.* [82] investigated the impact of a combined approach involving MI and AO on hand control abilities, focusing on healthy individuals. The experimental group underwent hand manipulation training with varying levels of difficulty, resulting in significant improvements in hand function. The study demonstrated that the combined MI and AO intervention activated the same brain regions involved in actual movements, even among severe stroke patients with limited active movement [82]. Furthermore, the findings highlighted that training effectiveness depends on the difficulty level; minimal improvement was observed when the training was either too easy or too challenging, both in healthy participants and later in stroke patients. Another study examined the muscular responses of stroke patients during combined AO and MI interventions. Seven stroke patients participated in the study, which utilized kinesthetic and visual imagery. Initial data showed no significant changes in reflex gain following a 5-minute training session. However, the study identified phase-dependent modulation of cutaneous reflexes during the gait phase, highlighting differences among the heterogeneous stroke patients. These findings suggest that stroke survivors exhibit gait-phase-specific reflex responses when engaging in combined AO and MI interventions [83].

BCI technology holds significant potential for enhancing neuroplasticity and facilitating motor recovery by modulating neurophysiological activity. Integrating MI instructions into BCI systems has emerged as an effective strategy, leveraging neurofeedback mechanisms to drive recovery. A recent meta-analysis demonstrated that BCI can induce functional and structural neuroplasticity changes, even at lower levels of activation [47]. However, the effectiveness of a BCI setup depends heavily on the user's ability to intentionally control their brain activity. Neuper *et al.* [84] explored the intricate relationship between user control and BCI performance. Their investigation examined the synergistic effects of combining AO and MI instructions to enhance input signals for BCI systems. Using electroencephalography, they observed significant modulations of sensorimotor rhythms when AO and MI instructions were employed concurrently. Another study focusing on BCI applications revealed that combining MI and AO interventions positively influenced imagery ability, reaction time, and muscle activation across various tasks [85]. As BCI research progresses, it is crucial to address potential limitations, particularly individual patient factors such as cognitive abilities and mental imagery proficiency. Tailoring BCI systems to accommodate these factors is essential for optimizing neuroplasticity and promoting motor recovery in personalized rehabilitation programs.

The combination of MI and AO represents a promising intervention for motor recovery in stroke patients. Although the current evidence suggests modest benefits, the small to medium effect sizes reported in the Chye *et al.* [29] movement meta-analysis should not diminish the practical significance of these improvements, particularly in clinical settings. The synergistic engagement of the mirror neuron system and motor-related brain regions during combined MI and AO enhances neural plasticity, making it a powerful tool for neurorehabilitation. Further research is required to optimize treatment protocols, including factors such as timing, frequency, and patient-specific considerations. However, the combined MI and AO approach provides a viable, flexible, and non-invasive alternative to traditional rehabilitation methods. Its potential applications extend beyond stroke-related impairments, offering utility in a wide range of rehabilitation contexts. By leveraging mental practice and observation, this approach can provide stroke survivors with a dynamic and accessible pathway to improved motor recovery. The characteristics of the included studies are shown in Table 1 (Ref. [23,79–83]).

6. Study Limitations

The combination of MI and AO therapy is a promising strategy for motor rehabilitation in stroke patients. However, the effectiveness of MI interventions may be reduced in individuals with poor imagery skills, as they often struggle to generate vivid mental images of movement. Conflicting evidence exists regarding the efficacy of MI training in stroke rehabilitation, underscoring the need for personalized approaches. Pre-treatment assessments, such as the Kinesthetic and Visual Imagery Questionnaire or mental chronometry tasks, can evaluate a patient's capacity for visual and kinesthetic imagery. For patients with low MI ability, interventions may prioritize AO or incorporate external cues to enhance outcomes. Stratification based on factors such as lesion location and injury severity can be achieved using tools such as the FMA or the Brunnstrom Stages of Motor Recovery [86,87]. Tailored imagery activities, graded according to the patient's baseline capacity, can help address individual differences in MI ability. Combining MI and AO can further improve engagement and compensate for poor imagery skills. Additionally, real-time sensory input, neurofeedback, or VR-based approaches can aid patients in developing stronger imagery abilities, enhancing the overall effectiveness of rehabilitation programs.

A study has shown that reduced parietal lobe function, whether due to stroke or inhibitory brain stimulation in healthy individuals, can significantly impair MI capacity [88]. The parietal lobe plays a pivotal role in executing MI tasks by facilitating the integration of sensory and motor information required to create realistic and vivid mental images of movement. Consequently, individuals with parietal lobe damage often experience the greatest challenges in performing MI, as the damage disrupts the brain's sensory and spatial processing. This limitation highlights the variability in neurorehabilitation outcomes based on MI, suggesting that such interventions may not consistently benefit all patient populations. Therefore, it is essential to account for individual differences, particularly the functional status of the parietal lobe, when implementing MI-based strategies in clinical practice. Emerging approaches, such as combining MI with AO and/or transcranial electric stimulation, hold promise for improving outcomes in patients with parietal lobe impairments. By modulating cortical excitability, promoting neuronal plasticity, and enhancing sensory-motor integration, these treatments may restore parietal lobe function and improve both motor recovery and imagery capacity. However, further research is required to explore these limitations in depth and to develop targeted rehabilitation techniques for diverse stroke patient profiles.

Despite these potential challenges, some stroke patients have shown improvements in motor skills through the combined use of MI and AO therapy. Future research should explore whether this approach facilitates neural reorganization in motor-related brain areas and prefrontal regions associated with cognitive functions. Evidence indicates that combined MI and AO training may provide benefits beyond those of AO or MI alone. However, it is essential to account for the potential limitations posed by post-stroke brain function, as these factors may affect the overall efficacy of combined MI and AO training therapy.

Table 1. Summary characteristics of included studies focusing on MI combined with AO-based therapy for stroke patients.

Participants	Intervention	Assessment	Outcome and Results	Reference
15 inpatients. Time since stroke: <2 months.	MI guided by synchronous AO (MISAO). MI guided by asynchronous AO (MIAAO). Duration: 8 s performance and 10 s pause. Frequency: twice/day/wk. Block training 15 repetitive trials for 4 weeks (supervised training).	Pinch strength test, Fugl-Meyer Assessment, and event-related power decrease.	MISAO activated sensorimotor cortex and improved brain plasticity during limb motor recovery. Improved event-related power decrease values between the two groups (dES >0.8). MISAO improved FMA and pinch strength test scores compared with MIAAO, enhancing sensorimotor cortex excitation, and facilitating faster neurorehabilitation in stroke patients.	[23]
45 patients (22, 23). Age: 53–73 years. Time since stroke onset: 2 to 8 months.	AO + MI, AO group Duration: 25 min/session. Frequency: 5 times/week, for 8 weeks occupational therapy and physical therapy. Duration: 30 min/day.	Motor evoked potential, Fugl-Meyer Assessment- Upper Extremity, Wolf Motor Function Test, and Motor Activity Log.	Changes in Fugl-Meyer Assessment: Upper Extremity and Motor Activity Log Amount of Use items in the experimental group. AO with MI is effective in enhancing upper extremity function and increasing cortical spinal cord activation in patients with severe stroke with limited movement.	[80]
10 participants Age: <75 years. Time since stroke onset: <6 months.	(AO+MI, AO, MI, Control) cup-stacking sequences (task). Frequency: once/week, 5 weeks and 16 mental trials each (white star on a black screen (3 s), a countdown (3 s), exposure to the cup-stacking sequence (13 s); totaling 48 trials per day).	Stroke Impact Scale (SIS), Action Research Arm Test (ARAT), and activities of daily living and instrumental activities of daily living (ADL/IADL).	AO+MI practice resulted in shorter movement execution times at retention relative to MI and an unpracticed control condition, and improved activities of daily living of patients.	[79]
51 participants (25, 26). Age: >18 years. Time since stroke onset: null	Intervention group Duration: ≥3 hours of rehabilitation services. Frequency: once/day, 5 days/week. Group synchronous AO/mental practice sessions. Frequency: 3 times/week. The control group received usual care.	Kinesthetic and Visual Imagery Questionnaire Short Version (KVIQ-10), Fugl-Meyer Assessment for Upper Extremity (FMA-UE), and Box and Block Test (BBT).	Fugl-Meyer Assessment- Upper Extremity, and Box and Block Test were significant between subgroups.	[81]
40 healthy subjects (10, 10, 10, 10) Age: 18–27 years. Time since stroke: null	MI+AO training, MI+AO 1.0, MI+AO 1.5, MI+AO 2.25. Frequency: 20 times, 15 s break between sets, 3 min break after 10 sets.	Visual Analogue Scale (VAS) and Kinesthetic and Visual Imagery Questionnaire (KVIQ).	There was an inverse U-shaped relationship between the difficulty levels of MI+AO training and motor skill improvement.	[82]
7 stroke patients. Age 26 to 74 years. Time since the stroke: 1–123 months.	AO+MI	Kinesthetic and Visual Imagery Questionnaire score and mental chronometry ratio.	Stroke survivors showed phase-dependent modulation of cutaneous reflexes.	[83]

MI, motor imagery; FMA, Fugl-Meyer Assessment; AO, action observation.

7. Future Perspectives: Incorporation of Motor Imagery and Action Observation Techniques With Other Modalities

In this concluding segment, we offer insights and reflections on the practical application of combined MI and AO therapy in neurorehabilitation. Our study highlights the unique therapeutic mechanisms of integrated MI and AO as potentially more effective strategies for stroke rehabilitation. This approach aims to stimulate discussion within the field, encouraging a thoughtful evaluation of the suitability and adaptability of MI and AO therapy across diverse clinical settings.

In conjunction with other modalities, the combination of MI and AO aims to advance neurorehabilitation by integrating these approaches with non-invasive brain stimulation techniques such as transcranial electric stimulation and transcranial magnetic stimulation, peripheral electrical or magnetic stimulation [89], as well as VR and neurofeedback. For example, combining MI and AO with VR can create immersive environments that enhance patient engagement, provide immediate feedback, and facilitate more efficient motor learning. Furthermore, by targeting specific neural circuits involved in motor execution and visualization, the integration of MI and AO with non-invasive brain stimulation can potentially amplify brain plasticity and motor recovery. The effectiveness of rehabilitation can be further optimized by tailoring these combined interventions to individual patient characteristics, such as imagery capacity and stroke severity. Adaptive, personalized protocols can deliver more focused and targeted approaches to motor recovery. Additionally, advancements in wearable sensors and AI-driven platforms are poised to play a critical role by providing real-time data, enabling dynamic adjustments to interventions, tracking progress, and ensuring better outcomes. These innovations hold significant potential to not only improve stroke rehabilitation outcomes but also extend the application of MI and AO to other neurological disorders.

AO therapy offers a more patient-friendly approach tailored to accommodate different patient preferences by engaging both active attention and passive processing mechanisms. In contrast, MI primarily relies on voluntary and intentional mental imagery. Future research should focus on developing protocols to facilitate a smooth transition from AO to MI, considering factors such as the physical environment, task design, timing, learning, emotions, and perspective, an approach known as PETTLEP imagery training [90]. PETTLEP enhances the vividness of imagery, making it more realistic and closer to actual experiences. Additionally, future smartphone applications could play a key role by providing educational resources, target-specific exercises, functional skills training, tutorials on ADLs, and access to assistive devices [91,92]. Collaborative efforts between app developers, clinicians, researchers, and stroke patients will be essential in refining app content and tasks. This collaboration ensures flexibility, user control, and the ability to gather valuable feedback, ultimately allowing for the customization of the therapy processes to meet each patient's specific needs.

8. Conclusion

Integrating MI and AO instructions enhances activity within the brain's motor regions more effectively than either AO or MI alone. This synergy positions combined AO and MI therapy as a valuable tool for rehabilitation practitioners, especially when supplemented by physical practice. This combined therapy can significantly influence neuroplasticity and improve motor outcomes in stroke patients. However, there is a critical need for rigorous, high-quality research to further substantiate and build upon these promising findings.

Author Contributions

AN: Writing — original draft, Formal analysis. CMV, LW and SL: Writing — review & editing, Formal analysis. FQ: Conceptualization and design, Formal analysis, Writing — review & editing. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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