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Update

Motor Imagery in Physical Therapist Practice

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Motor imagery is the mental representation of movement without any body movement. Abundant evidence on the positive effects of motor imagery practice on motor performance and learning in athletes, people who are healthy, and people with neurological conditions (eg, stroke, spinal cord injury, Parkinson disease) has been published. The purpose of this update is to synthesize the relevant literature about motor imagery in order to facilitate its integration into physical therapist practice. This update also will discuss visual and kinesthetic motor imagery, factors that modify motor imagery practice, the design of motor imagery protocols, and potential applications of motor imagery.

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Imagery refers to the "creation (or re-creation) of any experience in the mind—auditory, visual, tactile, olfactory, gustatory, kinesthetic, organic. It is a cognitive process employed by most, if not all, humans."[1] Imagery bridges diverse domains of knowledge from psychology to art.[2] Specifically, *motor imagery* (MI) is the mental representation of movement without any body movement.[3,4] It is a complex cognitive operation[5–8] that is self-generated using sensory and perceptual processes, enabling the reactivation of specific motor actions within working memory. Therefore, sensory-perceptual, memory, and motor mechanisms are included in broader definitions of the term.

Mental practice is the voluntary rehearsal of imagery scenes or tasks, whereas *motor imagery practice* refers specifically to the mental rehearsal of MI contents with the goal of improving motor performance.[9,10] The terms "motor imagery practice" and "mental practice" (or mental rehearsal) often are used interchangeably. Accordingly, in this update, we also will treat these terms as synonyms.

Surprisingly, although mental practice of a poem, a melody, or a role in a play is universally used by people, the mental practice of motor tasks until recently has been confined mainly to sports activities. The application of knowledge and principles of mental practice to rehabilitation began slowly in the late 1980s[11,12] and early 1990s.[13] The number of dynamic brain imaging studies published recently has stimulated the reexamination of MI for rehabilitation, because these imaging techniques have reduced the subjectivity associated with MI by elucidating the neural substrates that subserve MI.[14–17] Evidence for neural reorganization as a result of MI training is emerging as well.[18,19]

Because MI is inexpensive and accessible and because of the increasing number of reports about the benefits of MI in improving motor performance,[9,20,22] it seems appropriate to inform physical therapists about its use. The purpose of this update, therefore, is to synthesize the relevant literature about MI in order to facilitate its integration into physical therapist practice.

Evidence Supporting Effects of MI Practice

Motor imagery is practiced to improve motor performance and to learn motor tasks. Abundant evidence on the positive effects of MI practice on motor performance and learning has been published.[23–28] For individuals who are healthy or those who have health-related problems, the rehearsal or practice of imagery tasks has been proven to be either beneficial by itself or in addition to physical practice.[3,9,21,29] In addition, enhanced self-efficacy accompanies the motor effects of imagery practice for both individuals who are healthy and those who are not.[30–33]

Individuals Who Are Healthy and Athletes

Studies of individuals who are healthy have shown the enhancement of the performance of various aspects of motor control because of MI practice. These enhancements of performance include gains in strength (force production capacity) of selected muscle groups,[34,35] improved speed in arm pointing capacity,[36] increased range of motion of the hip joint when MI was added to proprioceptive neuromuscular facilitation,[37] and improved postural control in elderly people.[11,38]

Recently, the use of MI practice to facilitate the mastering of perceptuomotor professional skills such as nursing and surgery has been demonstrated.[39,40] Similar advantages might be produced by imagery practice of physical therapist manual techniques. For imagery applied in the sports context, positive effects have been reported in speed,[41,42] performance accuracy,[41,43] muscle strength, movement dynamics,[41,44] and motor skill performance (for a recent review, see Taktek[45]).

Patient Populations

Studies of MI in rehabilitation have been conducted mainly on people with neuromuscular conditions. This update will discuss evidence from studies of people who have had a stroke, people with a spinal cord injury (SCI), people with Parkinson disease (PD), and people with intractable pain.

Stroke. The majority of studies on MI practice have been conducted in the field of neurological rehabilitation, especially in stroke rehabilitation. Several review articles offer summaries of these studies.[9,29,46] Sharma et al characterized motor imagery as a "backdoor" to accessing the motor system and rehabilitation at all stages of stroke recovery because "it is not dependent on residual functions yet still incorporates voluntary drive."[29(p1942)]

In numerous clinical studies, the effects of physical therapy or occupational therapy interventions in isolation were compared with the effects of an approach that combined physical and MI practice. These studies consistently found that the greatest improvements in motor performance occurred with interventions that combined physical and mental practice, followed by physical practice alone, and then by MI practice alone, which was superior to no practice at all.[47,48]

For individuals with hemiparesis, promising findings were reported for enhancing reaching as well as for isolated movements of the hand and fingers.[49,50] Practice-related improvement in ankle movements as well as in sit-to-stand performance and activities of daily living (ADL) also were reported.[48,51,52] The adverse effects of unilateral neglect likewise were ameliorated after imagery practice, allowing patients to find routes and walk[53] as well as to improve on neuropsychological tests.[54]

The ability to apply MI as well as the contribution of MI practice to rehabilitation has been established for individuals with acute, chronic, mild, and severe hemiparesis.[29,55–57] Page and colleagues[26,47,52] demonstrated the advantage of motor imagery practice in 1 case report and 2 small randomized controlled trials (RCTs). In the most recent RCT, the 11 individuals in the chronic phase after stroke who mentally rehearsed ADL significantly improved compared with those who only had physical practice.[52]

Similarly, in an RCT, Liu and associates[51] investigated the relearning of functional tasks, such as household work, cooking, and shopping, using MI. After 15 practice sessions, significant gains were achieved in household and community tasks, gains that interestingly transferred to 5 unpracticed activities.[51] These gains were clinically meaningful with a 2-point increase, on average, in Functional Independence Measure scores, indicating an improvement in the patient's functional status from "moderate assistance" to "supervision."[51]

The ability of individuals with chronic hemiplegia to achieve functional gains through imagery practice has further been supported by reports of significant, long-standing improvement in wrist movements and object manipulation in 2 patients[50] as well as in the improvement in line tracing in 3 patients with right poststroke hemiparesis.[58] In patients with chronic stroke, daily home practice of moving tokens with the affected hand for a total period of 4 weeks was associated with significant improvement in task performance compared with the progress made by control group subjects.[49]

Although the evidence supporting preservation of imagery for people after a stroke is compelling, it cannot be universally applied to all patients with stroke.[59] For example, impairments in MI ability due to contralateral parietal and premotor lesions, especially with regard to upper-extremity pointing and rotation activities, have been identified.[60,61] Furthermore, despite evidence of preservation of MI after stroke, it appears that both accuracy and temporal coupling can be disrupted. Sharma et al[29] labeled this phenomenon "chaotic motor imagery." Yet, given the multitude of factors affecting imagery ability and rehearsal, a person with impaired ability can still practice MI.[29]

Spinal cord injury. For individuals with SCI, MI practice has not been reported to directly affect motor performance. Cramer and colleagues[62] trained 10 subjects with complete tetraplegia or paraplegia and 10 control subjects who were healthy to imagine movements of the tongue and foot. For people with SCI, the main outcome pointed to improvement in the function of nonparalyzed muscles. Cramer and colleagues[62] also found activation of cortical networks in congruence with imagery of specific movements, which suggested to them that brain motor system function can be modulated independently of voluntary motor control and peripheral feedback. They concluded that motor imagery training might have value as an adjunct to restorative interventions targeting post-SCI deficits.[62]

Activation of movement-related areas of the brain during engagement in MI in patients with chronic SCI also has been demonstrated in several other studies.[63–65] Finally, brain activity related to MI has recently been harnessed using an electroencephalogram-based brain-computer interface to produce hand or neuroprosthetic movements in patients with tetraplegia.[66,67] Obviously, further developments can be expected.

Parkinson disease. For individuals with PD, the ability to apply MI is controversial.[68–71] Only a few studies have looked at the effects of mental practice in this patient group. Data from one such study showed that patients with PD failed to learn a graphomotor task using imagery practice, whereas individuals with Huntington disease did show improvement. The authors interpreted these findings as disordered imagery ability resulting from deficits in dopamine inputs to the basal ganglia in patients with PD.[72] On the other hand, in a recent controlled group study, daily functions that deteriorated because of bradykinesia improved more in patients receiving combined physical and mental practice than in patients receiving only physical practice.[73] In patients with PD treated with dopaminergic stimulation, imagery-related enhancement in several sites of the brain was noted during the "on" phase but not the "off" phase.

Intractable pain. According to Moseley,[74–76] MI practice has been used to alleviate long-standing complex regional pain syndrome of the hand. The treatment approach, termed "graded motor imagery," is composed of 3 sequential phases. During the first phase, subjects learn to recognize the left or right image of their hands or feet, which are shown to them in various postures; in the second phase, they practice these postures via imagery of smooth and pain-free movements; in the last phase, they perform movements of both limbs using a mirror box that hides the affected limb. This method was developed over 3 successive studies and is based on the idea that treatment of these chronic pain syndromes should focus on "training the brain."[76,77] The results pointed to a significant and substantial reduction in pain related to the intervention and an increase in function of the involved limb, which was maintained at a 6-month follow-up. Future research in the direction of these pilot findings is highly warranted.

In summary, the majority of studies dealing with MI practice in people who are healthy and in patient populations show progress in the performance of the target practiced movements or motor tasks. Evidence of retention of practice gains[51,78] as well transfer to nonpracticed tasks[28,36,51] also is accumulating. Practice protocols, as expected, vary depending on the study population, the target movements or motor tasks, environmental conditions, and the priorities of the person conducting the study.

Types of Imagery

Imagery has been categorized as external (visual) and internal (kinesthetic).[79] External imagery can be of the person or of the environment, or both. The perspective the person uses to imagine can be either first person (kinesthetic or visual) or third person (visual).[80] The first-person perspective is related either to the person's view (sight) of the imagery contents or to its kinesthetic sensation. The third-person perspective is the visual imagery of scenes outside the person.

Definitions of external and internal imagery have evolved. Mahoney and Avener distinguished between external (visual) and internal (kinesthetic) imagery as follows: "In external imagery, a person views himself from the perspective of an external observer; internal imagery, on the other hand, requires an approximation of the real life phenomenology such that the person actually imagines being inside his/her body and experiencing those sensations that might be expected in the actual situation."[79] This relatively old definition has raised some debate, especially in the sports literature (for example, see Callow and Hardy[80]). In current psychological and clinical studies, the definition of visual imagery involves self-visualization of action, whereas kinesthetic imagery implies somesthetic sensations elicited by action.[3,4]

A somewhat different distinction between kinesthetic and visual imagery relates MI to kinesthetic imagery of one's own movements, whereas visual imagery is associated with spatial coordinates of a movement in the environment. Thus, visual imagery applies mainly to imagery of moving objects or to movement of another person in the imagined environment, although imaging one's own movement is also possible.[81]

Some authors[80] have divided visual imagery into internal and external imagery, which refer to imagery of one's own movement and of another person's movement, respectively. Yet, in the literature cited in this update, this distinction is not explicitly made; therefore, in the current context, the term "visual imagery" pertains to self-performance in a specific imagined environment.

Use of visual or kinesthetic motor imagery appears to be influenced by type of task and stage of learning. For learning a new motor task, Fery[82] demonstrated that visual imagery was more suitable for tasks that emphasized form, whereas kinesthetic imagery was better for those tasks that emphasized timing or coordination of the two hands. Visual imagery was more effective than kinesthetic imagery in the enhancement of stance postural stability, alluding to the dependence of stance stability on environmental factors.[83]

Hall et al[84] claimed that the instructions for using kinesthetic imagery were more effective for learning closed motor skills, whereas visual-based imagery were more appropriate for learning open motor skills. Regarding retention of practice gains, visual imagery was reported to be effective when environmental space, or patterned movement in a graphic task, were learned.[85,86] On the other hand, for a task involving hand accuracy performance, kinesthetic imagery led to better retention than visual imagery.[87]

Several factors influence the decision about which imagery category (visual or kinesthetic) to use in therapy. The first factor is that imagery of human movement is a cognitive operation that depends on the dynamic relationship among the individual, the movement, and the environment.[81] In addition, imagery perspectives should be determined by the nature of the task, the environment, and individual characteristics. Considering that the separation into visual and kinesthetic imagery is highly artificial,[80] perhaps even academic, the application of both visual and kinesthetic imagery appears feasible and appropriate for most individuals.

Factors Modifying MI Practice

Imagery Ability

In order to optimize the benefits from MI practice, the individual's ability to use imagery is a relevant consideration. Various recommendations and reservations regarding the screening of individual candidates for MI practice have been pointed out in the literature. Although none of these should be regarded as imperative, a short summary with relevance to physical therapy follows.

Imagery is a multifaceted capacity that differs between individuals.[88,89] Motor imagery ability usually is assessed by individual responses to ordinal rating scales. Three of these instruments are commented on in detail.

The Movement Imagery Questionnaire (MIQ)[90] and its short, revised version (MIQ-R)[91] are based on subjects' ratings of the ease of imaging predefined upper- or lower-extremity movements on a 7-point Likert scale. Before scoring each movement, subjects are asked to perform the movement. Movement imagery is rated twice, once for visual imagery of movement performance (subjects are asked to "see" themselves in their mind performing the task) and once for kinesthetic imagery (subjects are asked to feel their own body executing the movement task). Test-retest reliability of the MIQ and its internal consistency values (Cronbach alpha) were reported to be .87 and .89, respectively.[92–94] Corresponding reported values for the MIQ-R are .88 and .82, respectively.[94] Evidence of a direct relationship between MIQ scores and motor skill acquisition rate exists.[94]

The Vividness of Motor Imagery Questionnaire (VMIQ)[95] focuses on rating the vividness of imagery tasks. The questionnaire is a 48-item, 5-point scale. Like the MIQ, responses to half of the questions are based on visual imagery and responses to the other half are based on kinesthetic imagery. The reported test-retest reliability of the VMIQ is .76; the reported correlation between the visual and kinesthetic subscores of the VMIQ and the corresponding subscores of the MIQ were .65 and .49, respectively.[94,96]

Whereas the MIQ and the VMIQ were formulated for subjects who are healthy, a newer index—the Kinesthetic and Visual Imagery Questionnaire (KVIQ)—has been designed to evaluate imagery ability and has been validated on subjects who are healthy and people with disabilities. The KVIQ[94] uses a 5-point ordinal scale to assess the clarity of the image (visual: V subscale) and the intensity of the sensations (kinesthetic: K subscale) that the subjects are able to imagine from the first-person perspective. Items consist of simple movements, such as foot tapping and shoulder flexion, that can be performed more easily than the items in the MIQ and VMIQ.

Test-retest reliability was established for subjects who are healthy (intraclass correlation coefficient [ICC]=.72–.81) and for people who have had a stroke (ICC=.81–.90). The constructs of visual and kinesthetic ability were validated on a sample of individuals who had a stroke; who had lower-limb amputations, lower-limb immobilization, or blindness; and control subjects who were healthy. Application of the tool has yet to be determined; however, the short form with test questions can be administered quickly.

Information on the application of the MIQ, VMIQ as well as of the Sport Imagery Questionnaire[97] and its revised version[98] can be found in several references.[99–102] Only a few studies, all from the sports psychology literature, reported a positive relationship between scores on imagery scales and gains achieved by imagery practice[103]; many others have not found such an unequivocal connection.[44,104] Because the ability to access MI is, by itself, a faculty that can improved by practice in individuals who are healthy as measured by the VMIQ,[38] it appears that the initial scores on the scales described above should not be used to exclude patients from MI intervention.

Task Familiarity

Some authors have claimed that familiarity is a prerequisite for successful use of MI practice. Mulder and associates[105] found that after mental practice, motor performance of a new motor task (big toe abduction) improved substantially in a group of people who had previously mastered the task compared with the group with no previous practice. Mutsaarts et al[106] showed that individuals with hemiparetic cerebral palsy whose imagery ability was impaired were unable to plan novel tasks. Based on these findings, the authors advised avoiding imagery practice of completely new motor tasks.

In tangential work, Aleman et al[107] explored the ability of people with total congenital blindness to perform tasks that are mediated by visual mental imagery in people who are not blind. In contrast to previously cited reports on familiarity with imagery, Aleman and colleagues[107] found that people who are congenitally blind were able to perform tasks that are mediated by visual mental imagery in people who are not blind. Although the people who were blind made more errors than participants who were not blind, they were able to perform both a pictorial and a spatial imagery task. The authors maintained that their observations strongly suggest that vision and haptics share common representations and, therefore, haptic sensation can be substituted for the lack of visual information.[107] Imbiriba and colleagues[108] made similar conclusions for subjects who were blind.

We contend that the conflicting information on the role of familiarity in successfully using MI is masked by the multitude of operational definitions for terms such as "motor tasks" and "novelty" (contrast, for example, toe abduction with pointing to meaningful objects). Generalizations made from one study to other populations or conditions, therefore, should be made with caution. Nevertheless, the notion that effectiveness of mental practice is related to familiarity with the motor task, with familiar tasks being associated with better outcomes than practice of unfamiliar tasks,[109,110] should be considered when selecting patients and planning an intervention.

Working Memory

Working memory is a complex process that includes storage and manipulation of information; it can be categorized as visual, verbal, or kinesthetic.[10] The mutual relationship between working memory and imagery ability,[5,111] which underlies the inclusion of working memory in the broad definition of MI, is an important consideration.[29]

Malouin et al[10] observed that improvement in the performance of "sit to stand" after a combined physical and imagery intervention was enhanced in a group with intact working memory compared with a group with deficits in working memory. The strongest relationship was manifested in the visual-spatial domain (r=.83), followed by the verbal (r=.62) and kinesthetic (r=.59) domains. Malouin and colleagues, describing motor imagery as a "dynamic state during which the representation of a specific action is internally reactivated,"[10(p177)] further maintained that mental rehearsal requires that subjects maintain and manipulate visual and kinesthetic information in their working memory. An impairment in working memory, therefore, may hinder the ability to engage successfully in MI, and thus curtail the outcomes of mental practice.[10] Despite these reservations, it is worth noting that MI practice combined with physical practice was shown to enhance the performance of an anticipatory motor task more than physical practice alone in individuals with a high probability of deficits in working memory (eg, adolescents with mild mental retardation).[112]

Motivation

Findings on motivation and anxiety as modifiers to effective mental practice are equivocal. On the one hand, it is well substantiated that people who are highly motivated who use MI improve more than people who are not as highly motivated.[89,98,113] Similarly, people with low cognitive anxiety scores practiced better mentally than people with high anxiety scores.[31] On the other hand, engagement in mental practice may increase arousal and self-efficacy, thus having positive effect on motivation and self confidence.[30,82,101] Therefore, individuals with low motivation or anxiety should not be excluded, but rather should be encouraged to take part in MI practice.

Designing Imagery Protocols

It is widely accepted that MI practice is similar to physical practice except for the absence of neuromuscular output during imagery practice.[36,42,114] Thus, both physical and mental practices are self-generated, with the intent of improving performance and promoting motor learning.

Developing an intervention to achieve motor or task competence is largely comparable for real and imagined exercises; therefore, the same "rules" and concepts that underline the formulation of exercise therapy for solving a clinical problem apply to imagery practice.[114,115] This implies that, for both modes of exercises, interventions should planned and devised to respond to specific individual goals and movement problems at the appropriate level of impairment or function. In different sports, there are multiple models of mental practice that address different goals.[21]

In order to facilitate imagery practice, however, some established facts should be considered. First, challenging or unfamiliar actions are more difficult to imagine than simple or familiar ones.[116,117] Second, closed loop skills are easier to practice than open loop skills.[110] Third, gains from mental practice may be higher when imagery is used at the initial or cognitive phase of motor skill acquisition.[45,109] Positive effects of imagery practice during a later phase, which is thought to be the consolidation phase of motor learning, also have been suggested.[118]

Motor imagery practice is routinely applied under professional supervision during individual or group sessions. Mental practice also can be applied unsupervised for short periods of time. For example, precompetition rehearsal of specific activities for the enhancement of motor performance and self-efficacy is common in different sports.[100,119] Similarly, athletes who are injured frequently mentally rehearse a movement just before its actual performance.[120] Obviously, patients with difficulties in performing a motor task should be encouraged to use imagery routines before actual performance of a challenging motor task.

The following comments pertain to MI practice during supervised physical therapy intervention. Relaxation has been reported to promote favorable conditions for concentration by permitting the formation of vivid images.[119] Thus, MI practice is generally applied with subjects seating reclined or lying down with the eyes closed. Relaxation "exercises" to promote a relaxed state of body and mind precede actual imagery practice.[45,121,122] During practice, it has been recommended that the instructions of imagery exercises should be detailed and oriented towards either the visual or kinesthetic aspects of the task.[45]

Duration of MI practice is shorter than that of physical practice. Based on a meta-analysis of controlled studies of mental practice, the recommendation for treatment for people who are healthy is limited to 20 minutes.[123] In fact, there is a negative relationship between effect and increased practice duration.[123] For individuals with neurologic conditions, training duration might be even shorter, with protocols reporting training times of 12 to 15 minutes for individuals after a stroke.[122] It is relevant to add that part of the imagery training time may involve relaxation to prepare the person to imagine more effectively.[52,122]

Descriptions of MI clinical treatment protocols that could serve as guidelines for physical therapists are scarce and vary highly both in content and approach. Existing studies should be regarded as suggestions for protocols; one should bear in mind that these protocols were compiled by individual clinicians and researchers for a specific group of subjects under particular study conditions. Their partial or complete adoption by other therapists should be determined using sound judgment. For those seeking specific guidelines for implementation of motor imagery practice, the majority of the answers can be found in the literature related to motor learning and motor rehabilitation (eg, Magill,[124] O'Sullivan and Schmitz,[125] and Strangman et al[126]). The guidelines described by Suinn[27] for sport performance enhancement also are relevant.

For the sake of brevity, only few MI practice protocols are reviewed in some detail below. Other protocols can be found in the sports literature (for reviews, see Taktek[45] and Grouios[110]).

MI Used to Improve ADL and Upper-Extremity Use for Individuals After Stroke

Liu and colleagues[51] compared the relearning and transfer of ADL tasks and the retention of intervention gains in 2 groups of individuals who sustained a stroke, with one group receiving imagery and the second (control group) receiving conventional training of the same tasks. The intervention protocol included 3 practice sets, each composed of 5 ADL tasks, given for 1 hour, 5 days a week, for a period of 3 weeks. Mental practice of the easiest task set (put clothes on hanger and fold the laundry) was practiced in the first week, whereas the most difficult (go to a park and outdoors shopping) was practiced in the last week.

Before MI, explicit information (verbal, pictorial, video/film) on task characteristics and steps for its mastery was provided. A computer program guided patients in relearning the steps required to perform each of the 15 tasks. In addition, feedback on physical performance of the prior tasks practiced with MI was provided throughout the practice period. Compared with the control group, the MI group reached a significantly higher performance level on the trained tasks as well as on 5 untrained tasks tested at the end of the training program. There also was higher retention of performance level in the MI group at a 1-month follow-up compared with the control group.[51]

In another study, Page and colleagues[52] supplemented real exercise practice for individuals with chronic poststroke hemiparesis with 30 minutes of imagery practice (eg, reaching towards a cup) twice a week that was the same as the physical practice. The mental practice sessions were provided by audiotapes. They consisted of 5 minutes of relaxation followed by imagery practice of ADL tasks performed with the affected upper extremity. The final 3 to 5 minutes allowed patients to refocus into the room. Improvement in the function of the affected upper extremity related to the imagery training was reported at the completion of the 6-week program.[52]

MI Used to Improve Walking for Individuals After a Stroke

In case studies by Dickstein and colleagues,[78,122] gait was trained using a home-based MI practice program. Participants who had a stroke trained for 15 minutes, 3 times a week for 6 weeks, using both visual and kinesthetic imagery. While early practice sessions focused on ameliorating specific gait impairments, practice modules were gradually added over the 6-week period to integrate the performance of push-off and loading the affected lower extremity with the demands to increase gait speed and symmetry. The last 2 weeks were geared toward walking practice, which was customized to the individuals' needs. Participants were encouraged to practice the same protocol during their free time.[78,122] The enhancement in gait speed and single support time in the paretic limb and of the angular changes at the knees support specific aspects of the intervention.

Confirming Patient Engagement

One of the challenges in applying MI to practice is the persistent question of how a clinician knows if the individual is engaged in MI. There are several sources of validation for employment of MI. Dynamic brain imaging studies have confirmed the neural substrates associated with imagery as well as the reorganization resulting from MI training. The rich literature on this topic is beyond the scope of this update. Monitoring of autonomic nervous system functions has provided physiological correlates to the practice of MI. Mental chronometry serves as a clinical probe confirming engagement in MI. We briefly discuss autonomic monitoring and mental chronometry because they are relevant to practice.

Autonomic Monitoring

A comprehensive review of studies confirming autonomic alterations during MI was recently been provided by Guillot and Collet.[3] Accordingly, for each of 3 following physiological categories, 2 measures have pointed to mental practice related autonomic changes:

- for electrodermal responses: skin resistance and skin potential measurements were elicited;
- for thermovascular responses: skin blood flow and skin temperature recordings pointed to relaxation; and
- for cardiorespiratory changes: heart and respiratory rate increased in close association with increase in mental effort.

A detailed review of studies describing autonomic changes during imagery practice falls beyond the scope of this update. It is noteworthy, however, that, in the clinical setting, simple measurements such as heart rate can provide an estimate of patients' engagement in imagery practice. For example, Decety et al[127] demonstrated that as the intensity of an imagined bicycling exercise increased, so did the corresponding measurements of heart rate. Similarly, Fusi and colleagues[128] found that cardiorespiratory responses were comparable when individuals walked and imagined walking at slow speed.

Mental Chronometry

Another tactic to monitor engagement in imagery practice is mental chronometry. This strategy is based on the observation that duration of mentally simulated and executed motor tasks are comparable. This similarity was confirmed in several studies using different paradigms in subjects who were healthy,[36,129–131] and in several groups of patients. Sirigu and colleagues,[132] for example, showed in a patient with unilateral motor cortex damage a parallel slowing of the contralateral upper extremity during both real and imagined movements. In contrast, this temporal congruence was not present for individuals with parietal lobe damage.[60] In addition, imagined movements follow Fitt's law, pointing to preservation of the speed-accuracy trade-off during imagined movements by subjects who were healthy[116,133–135] as well as by selected patients with Huntington disease.[136]

Thus, knowing the time length of the physical act, the therapist can ask the patient to signal the beginning and termination of the imagery performance. A comparable time period of the imagery and physical performance of the task is considered to be evidence of engagement in motor imagery practice of the required task.

There are some important limitations to mental chronometry. It does not give information on MI vividness but only on the characteristics of time preservation.[132] In addition, the notion that the timing of mentally simulated actions closely mimic actual movement times is far from being absolute. In a recent review, Guillot and Collet[137] described that, in sports activities, the similarity between the durations of the same actual and imagined movements applied only for automatic movements such as cycling or walking. The authors claimed that when athletes simulate only dynamic phases of movement or perform MI just before competition, environmental and time constraints lead to an underestimation of actual duration. Conversely, complex attention demanding movements take longer to image. They further showed that the similarity between actual and imagined movement is greater in expert than in novice athletes.[137,138]

Potential Applications

Motor imagery interventions can also be combined with modeling and observation. These combinations appear to be natural complements based on work of mirror neurons in animal models (for a review, see Buccino et al[139]). Mirror neurons have been identified for hand, mouth, and foot actions in humans and appear to contribute to imitation, observation, and imagination of movement. These 3 processes share similar neural substrates with executed movements, making them useful additions to physical practice.[139]

An interesting and exciting possibility that takes advantage of individuals' abilities to imagine movement is the use of motor imagery to drive computer interfaces to navigate virtual worlds.[140] Morganti et al[140] used stylized representations of movements to drive motor behavior by having individuals imagine the completion of the image. Scherer and colleagues[141,142] have harnessed the electroencephalogram signals generated during the imagination of movement in person with cerebral palsy to distinguish between rest and imagination. More recently, this group has shown that imaging the movement of one's hand can be mapped to moving in a virtual environment,[142] as well as having imagination of walking transfer to walking in a virtual environment.[143] These applications of MI are in the feasibility testing phase, but the use of imagery for rehabilitation has promise.

Summary

Evidence that mental practice of MI improves motor and task performance exists for individuals who are healthy and is emerging for individuals with neurologic conditions. Brain studies have served to validate MI as a dynamic process with strong correlates to executed movement. Behavioral studies also have confirmed a correspondence between imagined and executed movements by preserved timing and similar speed-accuracy trade-offs. Guidance on how to select individuals who can imagine can be done using inventories, although there are no well-established exclusion criteria. The design of MI interventions can use principles from executed movement interventions. In addition, we know that some form of relaxation and combined use of kinesthetic and visual imagery strategies can be applied. Variables to consider in patient selection and MI practice application are familiarity with and type of task, motivation, and working memory. In general, exercise dosing appears to be smaller than that used for executed exercise, suggesting a potential efficiency of mental practice relative to physical practice. Several strategies are available to monitor MI engagement such as mental chronometry and cardiovascular and respiratory responses to exercise. Use of mental practice as a complement to physical practice seems warranted.

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References

1 Imagery [definition]. Available at: http://en.wikipedia.org/wiki/Imagery. Accessed January 23, 2006.

2 LeBoutillier N, Marks DF. Mental imagery and creativity: a meta-analytic review study. *Br J Psychol.* 2003;94:29–44.

3 Guillot A, Collet C. Contribution from neurophysiological and psychological methods to the study of motor imagery. *Brain Res Brain Res Rev.* 2005;50:387–397.

4 Solodkin A, Hlustik P, Chen EE, Small SL. Fine modulation in network activation during motor execution and motor imagery. *Cereb Cortex.* 2004;14:1246–1255.

5 Annett J. Motor imagery: perception or action? *Neuropsychologia.* 1995;33:1395–1417.

6 Jeannerod M, Decety J. Mental motor imagery: a window into the representational stages of action. *Curr Opin Neurobiol.* 1995;5:727–732.

7 Kosslyn SM, Ganis G, Thompson WL. Neural foundations of imagery. *Nat Rev Neurosci.* 2001;2:635–642.

8 Michelon P, Vettel JM, Zacks JM. Lateral somatotopic organization during imagined and prepared movements. *J Neurophysiol.* 2006;95:811–822.

9 Braun SM, Beurskens AJ, Borm PJ, et al. The effects of mental practice in stroke rehabilitation: a systematic review. *Arch Phys Med Rehabil.* 2006;87:842–852.

10 Malouin F, Belleville S, Richards CL, et al. Working memory and mental practice outcomes after stroke. *Arch Phys Med Rehabil.* 2004;85:177–183.

11 Fansler CL, Poff CL, Shepard KF. Effects of mental practice on balance in elderly women. *Phys Ther.* 1985;65:1332–1338.

12 Warner L, McNeill ME. Mental imagery and its potential for physical therapy. *Phys Ther.* 1988;68:516–521.

13 Decety J, Ingvar DH. Brain structures participating in mental simulation of motor behavior: a neuropsychological interpretation. *Acta Psychol (Amst).* 1990;73:13–34.

14 Chatto CA, Deutsch JE, Pillai J, et al. Brain activation during kinesthetic and visual imagery of walking [abstract]. *J Neurol Phys Ther.* 2005;29:195.

15 Deutsch JE, Fischer S, Liu W, et al. Representation of imagined and executed sequential finger movements of adults post stroke and healthy controls [abstract]. *J Neurol Phys Ther.* 2005;29:194.

16 Ehrsson HH, Geyer S, Naito E. Imagery of voluntary movement of fingers, toes, and tongue activates corresponding body-part-specific motor representations. *J Neurophysiol.* 2003;90:3304–3316.

17 Lacourse MG, Turner JA, Randolph-Orr E, et al. Cerebral and cerebellar sensorimotor plasticity following motor imagery-based mental practice of a sequential movement. *J Rehabil Res Dev.* 2004;41:505–524.

18 Lotze M, Cohen LG. Volition and imagery in neurorehabilitation. *Cogn Behav Neurol.* 2006;19:135–140.

19 Lotze M, Halsband U. Motor imagery. *J Physiol Paris.* 2006;99(4–6):386–395.

20 Dobkin BH. Plasticity in the sensorimotor and cognitive networks. In: Dobkin BH, ed. *The Clinical Science of Neurologic Rehabilitation*. 2nd ed. New York, NY: Oxford University Press; 2003:16–18.

21 Rushall BS, Lippman LG. The role of imagery in physical performance. *International Journal for Sport Psychology.* 1997;29:57–72.

22 Schmidt RA, Wrisberg CA. Mental rehearsal techniques. In: Schmidt RA, Wrisberg CA, eds. *Motor Learning and Performance*. 2nd ed. Champaign, Ill: Human Kinetics; 2000:22–225.

23 Dobkin BH. Neurobiology of rehabilitation. *Ann N Y Acad Sci.* 2004;1038:148–170.

24 Hardy L, Callow N. Efficacy of external and internal visual imagery perspectives for the enhancement of performance on tasks in which form is important. *Journal of Sport and Exercise Psychology.* 1999;21:95–112.

25 Liu KP, Chan CC, Lee TM, Hui-Chan CW. Mental imagery for relearning of people after brain injury. *Brain Inj.* 2004;18:1163–1172.

26 Page SJ, Levine P, Sisto S, Johnston MV. A randomized efficacy and feasibility study of imagery in acute stroke. *Clin Rehabil.* 2001;15:233–240.

27 Suinn RM. Mental practice in sport psychology: where have we been, where do we go? *Clinical Psychology: Science and Practice.* 1997;4:189–207.

28 Nyberg L, Eriksson J, Larsson A, Marklund P. Learning by doing versus learning by thinking: an fMRI study of motor and mental training. *Neuropsychologia.* 2006;44:711–717.

29 Sharma N, Pomeroy VM, Baron JC. Motor imagery: a backdoor to the motor system after stroke? *Stroke.* 2006;37:1941–1952.

30 Callow N, Hardy L, Hall C. The effects of a motivational general-mastery imagery intervention on the sport confidence of high-level badminton players. *Res Q Exerc Sport.* 2001;72:389–400.

31 Halvari H. Effects of mental practice on performance are moderated by cognitive anxiety as measured by the Sport Competition Anxiety Test. *Percept Mot Skills.* 1996;83(3 pt 2):1375–1383.

32 Martin K, Moritz S, Hall C. Imagery use in sport: a literature review and applied model. *Sport Psychologist.* 1999;13:245–268.

33 Paivio A. Cognitive and motivational functions of imagery in human performance. *Can J Appl Sport Sci.* 1985;10:22S–28S.

34 Sidaway B, Trzaska AR. Can mental practice increase ankle dorsiflexor torque? *Phys Ther.* 2005;85:1053–1060.

35 Zijdewind I, Toering ST, Bessem B, et al. Effects of imagery motor training on torque production of ankle plantar flexor muscles. *Muscle Nerve.* 2003;28:168–173.

36 Gentili R, Papaxanthis C, Pozzo T. Improvement and generalization of arm motor performance through motor imagery practice. *Neuroscience.* 2006;137:761–772.

37 Williams JG, Odley JL, Callaghan M. Motor imagery boosts proprioceptive neuromuscular facilitation in the attainment and retention of range-of-motion at the hip joint. *Journal of Sports Science and Medicine.* 2004;3:160–166.

38 Hamel MF, Lajoie Y. Mental imagery: effects on static balance and attentional demands of the elderly. *Aging Clin Exp Res.* 2005;17:223–228.

39 Bachman K. Using mental imagery to practice a specific psychomotor skill. *J Contin Educ Nurs.* 1990;21:125–128.

40 DesCoteaux JG, Leclere H. Learning surgical technical skills. *Can J Surg.* 1995; 38:33–38.

41 Blair A, Hall C, Leyshon G. Imagery effects on the performance of skilled and novice soccer players. *J Sports Sci.* 1993; 11:95–101.

42 Boschker MS, Bakker FC, Rietberg MB. Retroactive interference effects of mentally imagined movement speed. *J Sports Sci.* 2000;18:593–603.

43 Yue G, Cole KJ. Strength increases from the motor program: comparison of training with maximal voluntary and imagined muscle contractions. *J Neurophysiology.* 1992;67:1114–1123.

44 Yaguez L, Nadel D, Hoffman H, et al. A mental route to motor learning: improving trajectorial kinematics through imagery training. *Behav Brain Res.* 1998;90: 95–106.

45 Taktek K. The effects of mental imagery on the acquisition of motor skills and performance: a literature review with theoretical implications. *Journal of Mental Imagery.* 2004;29:79–114.

46 Jackson PL, Lafleur MF, Malouin F, et al. Potential role of mental practice using motor imagery in neurologic rehabilitation. *Arch Phys Med Rehabil.* 2001;82: 1133–1141.

47 Page SJ, Levine P, Sisto SA, Johnston MV. Mental practice combined with physical practice for upper-limb motor deficit in subacute stroke. *Phys Ther.* 2001;81: 1455–1462.

48 Malouin F, Richards CL, Doyon J, et al. Training mobility tasks after stroke with combined mental and physical practice: a feasibility study. *Neurorehabil Neural Repair.* 2004;18:66–75.

49 Dijkerman HC, Ietswaart M, Johnston M, MacWalter RS. Does motor imagery training improve hand function in chronic stroke patients? A pilot study. *Clin Rehabil.* 2004;18:538–549.

50 Stevens J, Stoykov ME. Using motor imagery in the rehabilitation of hemiparesis. *Arch Phys Med Rehabil.* 2003;84: 1090–1092.

51 Liu KP, Chan CC, Lee TM, Hui-Chan CW. Mental imagery for promoting relearning for people after stroke: a randomized controlled trial. *Arch Phys Med Rehabil.* 2004;85:1403–1408.

52 Page SJ, Levine P, Leonard AC. Effects of mental practice on affected limb use and function in chronic stroke. *Arch Phys Med Rehabil.* 2005;86:399–402.

53 Niemeier JP, Cifu DX, Kishore R. The lighthouse strategy: improving the functional status of patients with unilateral neglect after stroke and brain injury using a visual imagery intervention. *Top Stroke Rehabil.* 2001;8:10–18.

54 Smania N, Bazoli F, Piva D, Guidetti G. Visuomotor imagery and rehabilitation of neglect. *Arch Phys Med Rehabil.* 1997; 78:430–436.

55 Johnson SH, Sprehn G, Saykin AJ. Intact motor imagery in chronic upper limb hemiplegics: evidence for activity-independent action representations. *J Cogn Neurosci.* 2002;14:841–852.

56 Kimberley TJ, Khandekar G, Skraba LL, et al. Neural substrates for motor imagery in severe hemiparesis. *Neurorehabil Neural Repair.* 2006;20:268–277.

57 Crosbie JH, McDonough SM, Gilmore DH, Wiggam MI. The adjunctive role of mental practice in the rehabilitation of the upper limb after hemiplegic stroke: a pilot study. *Clin Rehabil.* 2004;18: 60–68.

58 Yoo E, Park E, Chung B. Mental practice effect on line-tracing accuracy in persons with hemiparetic stroke: a preliminary study. *Arch Phys Med Rehabil.* 2001;82: 1213–1218.

59 Johnson SH. Imagining the impossible: intact motor representations in hemiplegics. *Neuroreport.* 2000;11:729–732.

60 Sirigu A, Duhamel JR, Cohen L, et al. The mental representation of hand movements after parietal cortex damage. *Science.* 1996;273:1564–1568.

61 Tomasino B, Rumiati RI. Effects of strategies on mental rotation and hemispheric lateralization: neuropsychological evidence. *J Cogn Neurosci.* 2004; 16:878–888.

62 Cramer SC, Orr EL, Cohen MJ, Lacourse MG. Effects of motor imagery training after chronic, complete spinal cord injury. *Exp Brain Res.* 2006;177:233–242.

63 Alkadhi H, Brugger P, Boendermaker SH, et al. What disconnection tells about motor imagery: evidence from paraplegic patients. *Cereb Cortex.* 2005;15: 131–140.

64 Sabbah P, Leveque C, Pfefer F, et al. Functional MR imaging and traumatic paraplegia: preliminary report. *J Neuroradiol.* 2000;27:233–237.

65 Cramer SC, Lastra L, Lacourse MG, Cohen MJ. Brain motor system function after chronic, complete spinal cord injury. *Brain.* 2005;128:2941–2950.

66 Muller-Putz GR, Scherer R, Pfurtscheller G, Rupp R. EEG-based neuroprosthesis control: a step towards clinical practice. *Neurosci Lett.* 2005;382(1–2):169–174.

67 Muller-Putz GR, Scherer R, Pfurtscheller G, Rupp R. Brain-computer interfaces for control of neuroprostheses: from synchronous to asynchronous mode of operation. *Biomed Tech (Berl).* 2006;51: 57–63.

68 Frak V, Cohen H, Pourcher E. A dissociation between real and simulated movements in Parkinson's disease. *Neuroreport.* 2004;15:1489–1492.

69 Cunnington R, Egan GF, O'Sullivan JD, et al. Motor imagery in Parkinson's disease: a PET study. *Mov Disord.* 2001;16: 849–857.

70 Filippi MM, Oliveri M, Pasqualetti P, et al. Effects of motor imagery on motor cortical output topography in Parkinson's disease. *Neurology.* 2001;57:55–61.

71 Thobois S, Dominey P, Fraix V, et al. Effects of subthalamic nucleus stimulation on actual and imagined movement in Parkinson's disease: a PET study. *J Neurol.* 2002;249:1689–1698.

72 Yaguez L, Canavan AG, Lange HW, Homberg V. Motor learning by imagery is differentially affected in Parkinson's and Huntington's diseases. *Behav Brain Res.* 1999;102(1–2):115–127.

73 Tamir R, Dickstein R, Huberman M. Integration of motor imagery and physical practice in group treatment applied to subjects with Parkinson's disease. *Neurorehabil Neural Repair.* 2007;21:68–75.

74 Moseley GL. Graded motor imagery is effective for long-standing complex regional pain syndrome: a randomised controlled trial. *Pain.* 2004;108(1–2): 192–198.

75 Moseley GL. Is successful rehabilitation of complex regional pain syndrome due to sustained attention to the affected limb? A randomised clinical trial. *Pain.* 2005;114(1–2):54–61.

76 Moseley GL. Graded motor imagery for pathologic pain: a randomized controlled trial. *Neurology.* 2006;67:2129–2134.

77 Birklein F, Maihofner C. Use your imagination: training the brain and not the body to improve chronic pain and restore function. *Neurology.* 2006;67: 2115–2116.

78 Dickstein R, Dunsky A, Marcovitz E. Motor imagery for gait rehabilitation in post-stroke hemiparesis. *Phys Ther.* 2004;84: 1167–1177.

79 Mahoney MJ, Avener M. Psychology of the elite athlete: an exploratory study. *Cognitive Therapy and Research.* 1977; 1:135–141.

80 Callow N, Hardy L. The relationship between the use of kinaesthetic imagery and different visual imagery perspectives. *J Sports Sci.* 2004;22:167–177.

81 Stevens JA. Interference effects demonstrate distinct roles for visual and motor imagery during the mental representation of human action. *Cognition.* 2005; 95:329–350.

82 Fery YA. Differentiating visual and kinesthetic imagery in mental practice. *Can J Exp Psychol.* 2003;57:1–10.

83 Rodrigues EC, Imbiriba LA, Leite GR, et al. Mental stimulation strategy affects postural control [in Portuguese]. *Rev Bras Psiquiatr.* 2003;25(suppl 2):33–35.

84 Hall C, Buckolz E, Fishburne GJ. Imagery and the acquisition of motor skills. *Can J Sport Sci.* 1992;17:19–27.

85 Farahat E, Ille A, Thon B. Effect of visual and kinesthetic imagery on the learning of a patterned movement. *International Journal of Sport Psychology.* 2004;35:119–132.

86 White A, Hardy L. Use of different imagery perspectives on the learning and performance of different motor skills. *Br J Psychol.* 1995;86(pt 2):169–180.

87 Kim JG, Chung ST. Auditory, visual, and kinesthetic imagery on badminton service learning and performance. *Journal of Sport and Exercise Psychology.* 1998;20:S67–S67.

88 Isaac AR, Marks DF. Individual differences in mental imagery experience: developmental changes and specialization. *Br J Psychol.* 1994;85(pt 4):479–500.

89 Madigan R, Frey RD, Matlock TS. Cognitive strategies of university athletes. *Can J Sport Sci.* 1992;17:135–140.

90 Hall CR, Pongrac J. *Movement Imagery Questionnaire.* London, Ontario, Canada: Department of Physical Education, University of Western Ontario; 1983.

91 Hall CR, Martin KA. Measuring movement imagery abilities: a revision of the movement imagery questionnaire. *Journal of Mental Imagery.* 1997;21:143–154.

92 Atienza F, Balaguer I, Garcia-Merita M. Factor analysis and reliability of the Movement Imagery Questionnaire. *Percept Mot Skills.* 1994;78:1323–1328.

93 Hall CR. Individual differences in the mental practice and imagery of motor skill performance. *Can J Appl Sport Sci.* 1985;10:17S–21S.

94 Malouin F. The Kinesthetic and Visual Imagery Questionnaire (KVIQ) for assessing motor imagery in persons with physical disabilities: a reliability and construct validity study. *J Neurol Phys Ther.* 2007. In press.

95 Isaac A, Marks DF, Russell DG. An instrument for assessing imagery of movement: the vividness of movement imagery questionnaire (VMIQ). *Journal of Mental Imagery.* 1986;10:23–30.

96 Campos A, Perez M. A factor analysis study of two measures of mental imagery. *Percept Mot Skills.* 1990;71:71:995–1001.

97 Hall CR, Mack DE, Paivio A, Hausenblas HA. Imagery use by athletes: development of the sport imagery questionnaire. *International Journal of Sport Psychology.* 1998;29:73–89.

98 Cumming J, Hall C. Athletes' use of imagery in the off-season. *Sport Psychologist.* 2002;16:160–172.

99 Abma CL, Fry MD, Li YH, Relyea G. Differences in imagery content and imagery ability between high and low confident track and field athletes. *Journal of Applied Sport Psychology.* 2002;14:67–75.

100 Beauchamp MR, Bray SR, Albinson JG. Pre-competition imagery, self-efficacy and performance in collegiate golfers. *J Sports Sci.* 2002;20:697–705.

101 Short SE, Tenute A, Feltz DL. Imagery use in sport: mediational effects for efficacy. *J Sports Sci.* 2005;23:951–960.

102 Weinberg R, Butt J, Knight B, et al. The relationship between the use and effectiveness of imagery: an exploratory investigation. *Journal of Applied Sport Psychology.* 2003;15:26–40.

103 Goss S, Hall C, Buckolz E, Fishburne G. Imagery ability and the acquisition and retention of movement. *Mem Cognit.* 1986;14:469–477.

104 Corlett JT, Anton J, Kozub S, Tardif M. Is locomotor distance estimation guided by visual imagery. *Percept Mot Skills.* 1989;69:1267–1272.

105 Mulder T, Zijlstra S, Zijlstra W, Hochstenbach J. The role of motor imagery in learning a totally novel movement. *Exp Brain Res.* 2004;154:211–217.

106 Mutsaarts M, Steenbergen B, Bekkering H. Anticipatory planning deficits and task context effects in hemiparetic cerebral palsy. *Exp Brain Res.* 2006;172:151–162.

107 Aleman A, van Lee L, Mantione M, et al. Visual imagery without visual experience: evidence from congenitally totally blind people. *Neuroreport.* 2001;12:2601–2604.

108 Imbiriba LA, Rodrigues EC, Magalhaes J, Vargas CD. Motor imagery in blind subjects: The influence of the previous visual experience. *Neurosci Lett.* 2006;400(1–2):181–185.

109 Bohan M, Pharmer JA, Stokes AF. When does imagery practice enhance performance on a motor task? *Percept Mot Skills.* 1999;88:651–658.

110 Grouios G. Mental practice: a review. *Journal of Sport Behavior.* 1992;15(2):42–59.

111 Decety J, Grezes J. Neural mechanisms subserving the perception of human actions. *Trends Cogn Sci.* 1999;3:172–178.

112 Porretta DL, Surburg PR. Imagery and physical practice in the acquisition of gross motor timing of coincidence by adolescents with mild mental retardation. *Percept Mot Skills.* 1995;80(3 pt 2):1171–1183.

113 Cumming J, Hall C, Harwood C, Gammage K. Motivational orientations and imagery use: a goal profiling analysis. *J Sports Sci.* 2002;20:127–136.

114 Hall C, Bernoties L, Schmidt D. Interference effects of mental imagery on a motor task. *Br J Psychol*. 1995;86(pt 2):181–190.

115 Roure R, Collet C, Deschaumes-Molinaro C, et al. Autonomic nervous system responses correlate with mental rehearsal in volleyball training. *Eur J Appl Physiol Occup Physiol.* 1998;78:99–108.

116 Decety J, Jeannerod M. Mentally simulated movements in virtual reality: does Fitts's law hold in motor imagery? *Behav Brain Res.* 1995;72:127–134.

117 Parsons LM. Temporal and kinematicproperties of motor behavior reflected in mentally simulated action. *J Exp Psychol Hum Percept Perform.* 1994;20:709–730.

118 Feltz D, Landers D. The effects of mental practice on motor skill learning and performance: a meta-analysis. *Journal of Sport Psychology.* 1983;51:25–57.

119 Murphy SM. Imagery interventions in sport. *Med Sci Sports Exerc.* 1994;26:486–494.

120 Driediger M, Hall C, Callow N. Imagery use by injured athletes: a qualitative analysis. *J Sports Sci.* 2006;24:261–271.

121 Hardy L, Fazey J. *Mental Rehearsal: A Guide for Sports Performance*. Leeds, United Kingdom: National Coaching Foundation, Springfield Books; 1990.

122 Dunsky A, Dickstein R, Ariav C, et al. Motor imagery practice in gait rehabilitation of chronic post-stroke hemiparesis: four case studies. *Int J Rehabil Res.* 2006;29:351–356.

123 Driskell JE, Copper C, Moran A. Does mental practice enhance performance? *J Appl Psychol.* 1994;79:481–492.

124 Magill RA. *Motor Learning: Concepts and Applications*. 4th ed. Madison, Wis: Brown & Benchmark; 1993.

125 O'Sullivan S, Schmitz T. *Physical Rehabilitation: Assessment and Treatment*. Philadelphia, Pa: FA Davis; 2001.

126 Strangman G, Heindel WC, Anderson JA, Sutton JP. Learning motor sequences with and without knowledge of governing rules. *Neurorehabil Neural Repair.* 2005;19:93–114.

127 Decety J, Jeannerod M, Germain M, Pastene J. Vegetative response during imagined movement is proportional to mental effort. *Behav Brain Res.* 1991;42:1–5.

128 Fusi S, Cutuli D, Valente MR, et al. Cardioventilatory responses during real or imagined walking at low speed. *Arch Ital Biol.* 2005;143(3–4):223–228.

129 Jeannerod M, Frak V. Mental imaging of motor activity in humans. *Curr Opin Neurobiol.* 1999;9:735–739.

130 Papaxanthis C, Pozzo T, Skoura X, Schieppati M. Does order and timing in performance of imagined and actual movements affect the motor imagery process? The duration of walking and writing task. *Behav Brain Res.* 2002;134(1–2):209–215.

131 Papaxanthis C, Schieppati M, Gentili R, Pozzo T. Imagined and actual arm movements have similar durations when performed under different conditions of direction and mass. *Exp Brain Res.* 2002;143:447–452.

132 Sirigu A, Cohen L, Duhamel JR, et al. Congruent unilateral impairments for real and imagined hand movements. *Neuroreport.* 1995;6:997–1001.

133 Maruff P, Wilson PH, De Fazio J, et al. Asymmetries between dominant and non-dominant hands in real and imagined motor task performance. *Neuropsychologia.* 1999;37:379–384.

134 Cerritelli B, Maruff P, Wilson P, Currie J. The effect of an external load on the force and timing components of mentally represented actions. *Behav Brain Res.* 2000;108:91–96.

135 Maruff P, Velakoulis D. The voluntary control of motor imagery: imagined movements in individuals with feigned motor impairment and conversion disorder. *Neuropsychologia.* 2000;38: 1251–1260.

136 McLennan NL, Georgiou NL, Mattingley JL, et al. Motor imagery in Huntington's disease. *J Clin Exp Neuropsychol.* 2000; 22:379–390.

137 Guillot A, Collet C. Duration of mentally simulated movement: a review. *J Mot Behav.* 2005;37:10–20.

138 Guillot A, Collet C, Dittmar A. Influence of environmental context on motor imagery quality: an autonomic nervous system study. *Biology of Sport.* 2005;22:215–226.

139 Buccino G, Solodkin A, Small SL. Functions of the mirror neuron system: implications for neurorehabilitation. *Cogn Behav Neurol.* 2006;19:55–63.

140 Morganti F, Gaggioli A, Castelnuovo G, et al. The use of technology-supported mental imagery in neurological rehabilitation: a research protocol. *Cyberpsychol Behav.* 2003;6:421–427.

141 Neuper C, Scherer R, Reiner M, Pfurtscheller G. Imagery of motor actions: differential effects of kinesthetic and visual-motor mode of imagery in single-trial EEG. *Brain Res Cogn Brain Res.* 2005;25:668–677.

142 Leeb R, Scherer R, Keinrath C, et al. Exploring virtual environments with an EEG-based BCI through motor imagery. *Biomed Tech (Berl).* 2005;50:86–91.

143 Pfurtscheller G, Leeb R, Keinrath C, et al. Walking from thought. *Brain Res.* 2006; 1071:145–152.

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Motor Imagery in Physical Therapist Practice

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