Mental Practice for Relearning Locomotor Skills
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Over the past 2 decades, much work has been carried out on the use of mental practice through motor imagery for optimizing the retraining of motor function in people with physical disabilities. Although much of the clinical work with mental practice has focused on the retraining of upper-extremity tasks, this article reviews the evidence supporting the potential of motor imagery for retraining gait and tasks involving coordinated lower-limb and body movements. First, motor imagery and mental practice are defined, and evidence from physiological and behavioral studies in healthy individuals supporting the capacity to imagine walking activities through motor imagery is examined. Then the effects of stroke, spinal cord injury, lower-limb amputation, and immobilization on motor imagery ability are discussed. Evidence of brain reorganization in healthy individuals following motor imagery training of dancing and of a foot movement sequence is reviewed, and the effects of mental practice on gait and other tasks involving coordinated lower-limb and body movements in people with stroke and in people with Parkinson disease are examined. Lastly, questions pertaining to clinical assessment of motor imagery ability and training strategies are discussed.
Over the past 2 decades, much work has been carried out on the use of mental practice through motor imagery for optimizing the retraining of motor function in people with physical disabilities. Although much of the clinical work with mental practice has focused on the retraining of upper-extremity tasks, in this article we will review the evidence supporting the potential of motor imagery for retraining gait and tasks involving coordinated lower-limb and body movements. First, we will define motor imagery and mental practice and examine evidence from physiological and behavioral studies in healthy individuals supporting the capacity to imagine walking activities through motor imagery. Then the effects of stroke, spinal cord injury (SCI), lower-limb amputation, and immobilization on motor imagery ability will be discussed. Evidence of brain reorganization in healthy individuals following motor imagery training of dancing and of a foot movement sequence will be reviewed, and then the effects of mental practice on gait and other tasks involving coordinated lower-limb and body movements in people with stroke and in people with Parkinson disease will be examined. Lastly, questions pertaining to clinical assessment of motor imagery ability and training strategies will be discussed.

Defining Mental Practice and Motor Imagery

Motor imagery is the imagining of an action without its physical execution; it is an active process during which the representation of an action is internally reproduced within working memory without any overt output. Mental practice or motor imagery practice, on the other hand, is the repetition or rehearsing of imagined motor acts with the intention of improving their physical execution. Mental practice of locomotor skills thus requires the ability to form internal representations of locomotor activities. Movement representations can be made from 2 perspectives: (1) from the third-person perspective (or external imagery), as spectator, when imagining another person walking or (2) from the first-person perspective (or internal imagery), from the inside as if the actor, when imagining oneself walking. Each perspective has different properties. The external perspective implies primarily a visual representation of the motor task, whereas the internal perspective entails, in addition to the visual representation, the kinesthetic sensations associated with the simulated movements, thus both visual and kinesthetic cues.

What Evidence Do We Have That Locomotor Activities Can Be Imagined Through Motor Imagery?

Experimental studies have used different approaches to examine the mental representation of locomotor activities in individuals without disabilities. Our understanding of motor imagery of walking comes from neurophysiological and cerebral imaging studies examining the similarities between real and simulated locomotor activities. These studies have shown that locomotor activities, either performed physically or imagined, are subject to common laws and principles. For instance, autonomic studies that monitored changes in heart and respiration rates while healthy individuals imagined walking on a treadmill at different speeds showed speed-related increases during the imagination of walking. Mental chronometric studies comparing movement times in people walking or imagining walking to targets placed at different distances showed the duration of walking to be similar in both conditions, thus indicating a temporal coupling between the duration of real and imagined walking conditions.

Moreover, when people walk or imagine themselves walking on narrow beams, through gates or along paths of different widths, uphill or downhill, and at different speeds, both the actual and imagined walking times increase as a function of the difficulty of the task. The latter findings thus indicate that Fitts’ law, which states that more-difficult movements take more time to produce physically than easier movements, also applies to motor imagery of walking.

Further confirmation of functional similarity between real walking and imagined walking comes from functional brain imaging studies. Direct comparison of cortical activity evoked during actual gait and the imagination of gait with near-infrared spectroscopy have shown that actual and simulated walking increase brain activity bilaterally in the primary sensorimotor cortices and the supplementary motor area (SMA). These findings have been confirmed with positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). Further demonstration that cortical brain areas are engaged during locomotor activities comes from PET and fMRI studies that examined brain activation patterns during the imagining of standing, initiating gait, normal walking, walking with obstacles, precision gait, walking along a curved path, and running and during the imagining of other complex movements involving the whole body (eg, swimming, dancing, lifting a heavy box).

Altogether the findings from the functional brain imaging studies confirm that the simulation of locomotor activities and complex whole-body tasks result in the activation of cortical networks similar to those found during motor imagery of simple movements, thus suggesting that the overlapping among neural substrates during real and
imagined movements also applies to complex body movements.\textsuperscript{21}

In summary, mentally simulated and physically executed locomotor activities share similar autonomic responses and temporal organization and activate neural networks that greatly overlap. Consequently, it has been suggested that the benefits of mental practice training are linked to the activation of cerebral networks that are comparable to those activated during physical execution.\textsuperscript{2,21}

Is Motor Imagery Ability Affected by Central and Peripheral Lesions of the Nervous System?
Because the ability to form internal representations of motor acts is necessary for training with mental practice, there is a need to determine whether this ability is specifically affected following central nervous system (CNS) or peripheral nervous system (PNS) lesions. Because of its concealed nature, however, motor imagery is difficult to assess.\textsuperscript{22–24}

Three main approaches have been used to assess motor imagery ability in clinical settings: mental rotation, mental chronometry, and questionnaires. Mental rotation is used to measure the accuracy of motor representations. In this approach, people are asked to verbally judge the laterality of hands or feet from pictures in different postural conditions. Behavioral and functional neuroanatomy studies have demonstrated that mental rotation of body parts is carried out through a sort of inner motor simulation.\textsuperscript{25,26} Mental chronometry involves the comparison of movement times during the simulation and execution of a motor task in various conditions (fast and slow paces or over short and long time periods); it is used to examine temporal organization of simulated actions.\textsuperscript{10,27–30} Lastly, the clarity and details of the images and the intensity of the sensations (vividness) perceived during movement simulation are assessed with motor imagery questionnaires.\textsuperscript{24,51}

After Stroke
Motor imagery ability has been studied extensively in people with cerebral lesions. The findings indicate that the representation of movement remains possible after stroke,\textsuperscript{24–26,28} even in people with chronic or severe motor impairments,\textsuperscript{26} suggesting that the mental representation of movement is not dependent on motor activity following CNS injury. To date, only a few patients with focalized lesions in the superior region of the parietal cortex\textsuperscript{29} or the frontal cortex\textsuperscript{25} have shown motor imagery impairment. Recently, findings in patients with stroke and age-matched healthy subjects who were assessed with the Kinesthetic and Visual Imagery Questionnaire (KVIQ)\textsuperscript{31} revealed that the level of motor imagery vividness following stroke was similar to that of healthy subjects, with good and bad imagers in both groups\textsuperscript{24} (Fig. 1). Likewise, using a left- or right-hand judgment task that implicitly requires motor imagery (mental rotation), Johnson and colleagues\textsuperscript{26} found that people with
stroke and healthy subjects had a range of accuracy scores that was similar in both groups, with very accurate subjects (above 90%) and less-accurate subjects (above 65%) in each group.26 This wide range of scores in accuracy and vividness of motor imagery indicates that motor imagery ability is not an all-or-none phenomenon; rather, there is a continuum in the level of performance, and in some cases the difficulty in forming internal representations of movement can be a premorbid trait unrelated to cerebral damage.24

Although these clinical studies focused mainly on the representation of simple limb movements, findings from a chronometric study in a group of people with stroke and a control group who were asked to physically execute and imagine the Timed “Up & Go” Test (TUG) indicate that the temporal representation of this complex locomotor task is retained following stroke.32 The variability in the movement times during imagination and execution conditions in the group with stroke was very similar to that observed in the control group (Fig. 2: upper graphs), and there was no significant difference between the mean imagination times and execution times for each of the subtasks in both groups. Moreover, the relative percentage of time dedicated to each subtask was similar in both groups (Fig. 2: lower graphs). These results imply that both the temporal coupling and the temporal structure of the TUG are retained after stroke. Such findings are notable because they indicate that the ability to rehearse mentally complex motor tasks is preserved after stroke.32

Figure 2.

After Complete Spinal Cord Injury
Findings from behavioral10 and fMRI studies33–35 indicate that the representation of foot movements is retained in people with complete SCI. Indeed, scores of motor imagery vividness after complete SCI are similar to those of control subjects, and the extent of brain activation during imagery of foot movements correlates with the vividness of their imagery.33–35 The persistence of motor representations in the disconnected limbs after a complete SCI is further evidence that motor imagery is maintained even when voluntary movements are not possible.

After Limb Amputation and Limb Immobilization
Although motor imagery ability following cerebral lesions24–26,28 and spinal lesions33–35 is retained even when physical movements are impaired or impossible, findings indicate that motor imagery ability is diminished by the lack of movement after the loss of a limb36,37 or temporary disuse following limb immobilization.37 More specifically, although the representation of movements is still present after upper-limb amputation, it has been shown to be less accurate during a left- or right-hand judgment task in people with an upper-limb amputation, suggesting that the absence of a limb does not prevent motor imagery, but makes it more difficult.36 Similarly, motor imagery vividness after lower-limb amputation is significantly decreased for foot movements of the missing limb,37 further demonstrating that although it is still possible to generate a mental representation of movement, the vividness of these images is weaker after the loss of a limb. Similar changes of motor imagery vividness were found in subjects who had an ankle immobilized in a cast for 2 to 4 weeks without weight bearing.37 A significant decrease in motor imagery vividness for move-
ments of the foot (the distal segment that was immobilized) also was observed. Such findings are remarkable, given the short period of immobilization, and imply that changes in motor imagery vividness with limb disuse can take place relatively quickly. Most interesting is the significant positive correlation ($r > .79$) found between the onset of walking with a prosthesis and scores of motor imagery vividness on the amputated side, which suggests that prosthesis use helps in maintaining the mental representation of the missing limb. In contrast, after the immobilization of one lower limb, the positive correlation ($r > .90$) between motor imagery vividness and the duration of immobilization found in the intact limb suggests that the augmented use of the intact limb, due to longer periods of immobilization, promoted imagery vividness on that side. Overall, these findings indicate that after limb amputation and disuse, the mental representation of actions is retained but weaker and highly modulated by sensorimotor inputs.37

What Evidence Do We Have That Mental Practice Training of Tasks Involving Coordinated Lower-Limb and Body Movements Induces Brain Reorganization?

To date, 2 studies have investigated changes in brain activation patterns in people who used mental practice to learn sequences of leg movements and a foot movement sequence.38 and 39 Sacco and colleagues38 found that, in contrast to subjects who only physically practiced sequences of leg movements through tango lessons (45 minutes a day for 5 days), those who rehearsed the sequences mentally (15 minutes a day for 5 days) in addition to physical practice showed an expansion of the bilateral motor areas. In addition, there was a reduction of the visuospatial activation in the posterior cortex, suggesting that focusing a subject’s attention on the foot movements involved in dancing decreases the role of visual imagery processes in favor of motor-kinesthetic processes.38 Likewise, changes in brain activity found in the medio-sagittal aspect of the orbitofrontal cortex (increase) and cerebellum (decrease) reported after intense mental practice (300 repetitions a day for 5 days) of a sequence of foot movements further support the notion that mental practice through motor imagery initially improves performance by acting on motor preparation and planning.38,40 Although foot movements seem remote from the more-complex limb and body movements in walking, a recent transcranial magnetic stimulation (TMS) study41 that examined how corticospinal excitability was affected by motor imagery of foot dorsiflexion and motor imagery of gait showed a close relationship in the control of the tibialis anterior muscle during motor imagery of simple foot dorsiflexion and gait. The findings of that study indicate that corticospinal effects of a simple motor imagery task can predict corticospinal effects of a more-complex motor imagery task involving the same muscle.

Does Mental Practice Training Improve the Performance of Gait and Other Tasks Involving Coordinated Lower-Limb and Body Movements in People With Stroke and in People With Parkinson Disease?

Gait

Mental practice with motor imagery provides an opportunity to improve locomotor skills through safe and self-paced locomotor training in people with severe disability thatrenders walking practice difficult and limited in time, especially in the early phase of rehabilitation.2,42-43 Yet, the potential use of mental practice for optimizing the relearning of activities such as walking and rising from a chair and sitting, as well as sequential foot movements, has been examined mainly in exploratory studies and case reports with small sample sizes.

Dickstein and colleagues43-45 have developed a motor imagery training program for gait rehabilitation post-stroke. The effects of this training program were first described in a case report of a 69-year-old man with left hemiparesis, and later the feasibility of using this motor imagery training at home was examined in 4 case studies.44 Dunskey and colleagues45 recently investigated the effects of this home-based motor imagery program in a group of 17 people poststroke to confirm and extend previous findings. Motor imagery training in the gait rehabilitation program consisted of 15- to 20-minute sessions, 3 times a week for 6 weeks, without any physical intervention. Both internal and external perspectives of motor imagery were used. The main objectives of training were to facilitate movements of the affected lower limb and improve posture by focusing on specific problems (eg, forefoot initial contact, push-off) and to promote functional walking in the patient’s own environment. The complexity of the task during motor imagery was increased progressively from familiarization with motor imagery of walking in an isolated place, on flat terrain and without disturbance (week 1), to more-complex situations such as imagining walking toward meaningful targets in the patient’s home and outdoors to increase gait speed and symmetry (weeks 5 and 6). Spatiotemporal parameters (gait speed, step length,
single-leg support) and some kine-
matic variables (knee extension at
initial foot contact) served as out-
come measures. Most patients in-
creased their gait speed, with gains
ranging from about 10% to 80%, for a
mean increase of 15 cm/s.45 The ef-
fect size was 0.64, corresponding to
a moderate treatment effect. In addi-
tion to a gain in gait speed, stride
length increased by 18% and single-
leg stance time increased by 13%,
indicating an improvement in mobi-
ity and dynamic balance.45 Most of
the gains were retained at follow-up
(3 weeks after the end of training).

Such a substantial improvement
raises much interest because it sup-
ports the idea that walking skills can
be enhanced by mental practice. How-
ever, because it has been shown
that mental practice of upper-limb
movements led to an increase in the
physical use of the trained extremi-
y,49,50 an increase in real walking
over the 6-week training program
also is likely. Thus, as the amount of
real walking over the 6-week training
period was not monitored in the
study by Dunsky and colleagues,45
the extent of motor improvement
attributed to mental practice must be
interpreted with caution because the
gains, in part, could be due to more
walking. Further studies con-
trolling for walking activities during
the training program are needed to
validate the contribution of mental
practice to the extent of the gains
reported.

In a recent controlled study of peo-
ple with Parkinson disease, evidence
that mental practice could help in
reducing bradykinesia during the
TUG task was provided when the
group of patients who combined
physical and mental practice over a
12-week period showed faster per-
formance than the group who
trained physically only.51 An impor-
tant limitation of this study and of
many others is the lack of informa-
tion about treatment adherence over
the 12 week-program and the
amount of physical locomotor train-
ing received by patients in each
group.

**Coordinated Lower-Limb and
Body Movements**

Beneficial effects of one session of
mental practice in 12 people with
chronic stroke were found in a study
that examined the effects of mental
practice in combination with a small
amount of physical practice (7 se-
ries, each consisting of 1 physical
repetition and 5 mental repetitions)
to improve the amount of loading on
the affected leg during rising from a
chair and sitting down.46-47 The load-
ing on the affected leg after training
significantly improved by 17.9% and
16.2%, respectively, when rising
from the chair and sitting down.
Gains were still significant 24 hours
later during rising (12.8%) and sitting
down (11.2%), indicating that learn-
ing had occurred. Patients with def-
cits in at least 2 domains of working
memory had a smaller improvement
(27% versus 72%) and showed no
retention at follow-up, suggesting
that learning effects are strongly re-
lated to working memory abilities.46
In contrast, the duration of the task
did not change with training. The
latter findings suggest that, in the
early stage of learning a complex mo-
tor task, changes in motor strategies
predominate over changes in speed
of execution and that, at this stage,
vertical forces (limb loading) repre-
sent a more-sensitive measure of per-
formance than movement time. Al-
though, this study had no control
group and did not tease out the spe-
cific effects of mental practice, the
gains achieved with a relatively small
amount of physical practice (7 phy-

c-321 repetitions and 35 mental repete-
tions) had a magnitude similar to
those measured after 3 weeks of reg-
ular physical training.52

One reason for retention of gains
with such little physical practice is
the combination of physical practice
with mental practice that requires
the person to mentally and explicitly
rehearse the sequence of move-
ments associated with the mobility
task. Such rehearsal makes the per-
son focus each time on the prepara-
tion and planning of the proper stra-
tegy, thus increasing his or her
awareness of the required move-
ments. Such an interpretation is in
line with the results of Pascual-Leone
and colleagues,40 who, using TMS,
demonstrated that mental practice
has preparatory effects and increases
the efficiency of subsequent physical
training. Another possible explana-
tion for retention of the gains after
only one mental training session
could be the consolidating effect of
sleep on motor learning, which was
reported recently following mental
practice in individuals who were
healthy.53

Additional support for the priming
or added effects of motor imagery on
motor performance comes from the
findings of a pilot study54 showing
that a small number of physical rep-
etitions alone (total of 120 repeti-
tions over a 4-week period) did not
enhance the motor performance
(limb loading of the affected leg dur-
ing rising-up and sitting-down tasks).
When these relatively few physical
repetitions were combined with a
large number of mental repetitions
(total of 1,100 repetitions), however,
the loading on the affected leg was
significantly increased and was re-
tained 3 weeks after training.

Another example pertaining to the
effect of combining physical prac-
tice and mental practice on lower-
limb function is a case study that
investigated the effect of mental
practice on the learning of a foot
movement sequence task in a 38-
year-old man with a left hemorrhagic
subcortical stroke.48 During the first
2 weeks, the patient physically practiced a serial response time task with the lower limb. The next week mental practice was combined with physical practice, and then the patient practiced only mentally for 2 weeks at home. The patient’s average response time improved significantly during the first 5 days of physical practice (26%), but then failed to show improvement. The combination of mental practice and physical practice during the third week yielded an additional improvement (10.3%), and the following 2 weeks of mental practice resulted in a marginal increase in performance (2.2%). These findings indicate that the addition of mental practice when the performance has reached a plateau can lead to further improvement in the performance of a sequential motor skill.48 Moreover, the retention of the motor skill with motor imagery practice alone at home suggests that mental practice can play a role in the retention of newly acquired abilities.48

In summary, although results from these clinical studies suggest that mental practice can lead to improvements in gait and other tasks involving coordinated lower-limb and body movements after stroke, randomized clinical trials with larger samples are needed to confirm and generalize findings about the effects reported so far in a small number of subjects. Yet, despite shortcomings of their designs, these case reports and feasibility and exploratory studies have provided useful data about the patients’ ability to adhere to diverse training approaches, the sensitivity of outcome measures, and the amount of training required to obtain significant clinical improvements.

What Do We Know About the Clinical Assessment of Motor Imagery Ability and Motor Imagery Training Strategies?

Clinical Assessment

The inclusion of mental practice in rehabilitation training strategies is still relatively new. Consequently, strategies and guidelines for its use as an adjunct therapy to promote the relearning of functional activities such as walking are under development. Because mental practice through motor imagery requires the representation of an action that is internally reproduced within working memory,1 good cognitive function and communicative skills are necessary. Clinical studies have used different approaches to test cognition, but a common test is the Modified Mini-Mental State Exam, with an inclusion score of 24/30 or more.45 A normal working memory in 2 domains (eg, visuospatial, verbal, kinesesthetic) also has been suggested.46 Patients with severe communication problems were excluded from most studies because of their difficulty in understanding the verbal instructions and in expressing themselves in order to actively participate in the assessment of motor imagery and in the learning of imagery.2,39,47

The next step is to assess motor imagery ability because it may be deficient as a result of the nature of the injury or simply as a premorbid trait.24 Because of its complex nature, however, more than one assessment tool should be used to determine whether a person is able to engage in motor imagery.22–24 Recently, the combination of the Time Dependent Motor Imagery (TDMI) screening test55 and the KVIQ,24,51 2 measures that are simple and easy to use in a clinical setting, has been proposed as a clinical assessment procedure.24 The TDMI is a chronometric screening test wherein the examiner records the number of movements imagined (eg, stepping movement) over 5 time periods (15, 25, and 45 seconds); it assumes that individuals who report an increase in the number of movements imagined with increasing time are able to simulate movements and likely engage in motor imagery24,57,55 (Fig. 3). Similar chronometric tests can be applied to locomotor tasks. For instance, whether patients are really imagining walking can be verified by asking them to imagine themselves walking along a short versus a longer path or along a wide versus a narrow path. If the patients really engage in motor imagery, movement times while imagining walking are expected to increase with increasing distance5,8,12 and decrease with increasing pathway width.3,11 Likewise, autonomic responses (heart or respiratory rates) also could be monitored during the imagination of walking at slow and fast speeds; cardiorespiratory responses are expected to increase at faster walking speeds.5–7 Lastly, when scheduling patients for assessing motor imagery, care should be taken to keep track of the time of the day because, contrary to real walking, the duration of the imagination of walking is influenced by the time of day.56

The KVIQ is a motor imagery questionnaire developed for people with physical disabilities that assesses the vividness of motor imagery from a first-person perspective51 and uses a 5-point scale to rate the clarity of the image (visual subscale) and the intensity of the sensations (kinesthetic subscale). It consists of 20 items (10 movements in each subscale) representing gestures with different body parts (head, shoulders, trunk, upper and lower limbs), and all movements are performed from a sitting position. Both the TDMI and the KVIQ have been standardized, and their test-retest reliability in people with stroke has been confirmed.51,55 Of a
sample of 37 patients with chronic stroke who underwent these evaluation procedures, only 2 patients failed the chronometric screening test, and the KVIQ revealed that 3 patients who had passed the screening tests had difficulty in forming mental images of movement. Thus, although patients may pass the chronometric test, they may have difficulty in generating vivid internal representations of movements. Failure to adhere to the KVIQ also has been observed occasionally in people who were healthy. The assessment procedures provide not only an idea on the motor imagery ability of the patient but also a good introduction to the notion of motor imagery that prepares the patient for mental practice training.

**Validity of Motor Imagery Questionnaires**

The validity of imagery questionnaires for assessing motor imagery ability has been questioned, given the subjective nature of self-reported ratings. However, over the past few years, several studies examining brain activation patterns or motor cortex excitability during the imagination of movements have shown strong relationships between imagery vividness scores and the level of brain activations, suggesting that ratings from imagery questionnaires provide a good indication of the ability to generate vivid mental images of movement. Recently, in an fMRI study of subjects allocated to bad and good imager groups based on combined scores from a motor imagery questionnaire, mental chronometry and electrodermal responses—2 distinct functional neuroanatomical networks, each specific to either the good or bad imagers—were described. The latter findings provide further evidence of a link between behavioral outcome measures and functional neuroanatomical networks. Finally, in a recent study in people with lower-limb amputation, the agreement between KVIQ scores, which are based on an explicit imagery paradigm (the individual is asked to imagine a movement), and scores obtained by Nico and colleagues, who used an implicit imagery paradigm (ie, mental rotation, in which the individual is asked to verbally judge the laterality of hands and feet portrayed in pictures in different postural conditions), provides additional support for the validity of motor imagery questionnaires.

**Training Strategies**

Results from behavioral, psycho-physical, and brain imaging studies in athletes and healthy individuals provide some guidelines for training strategies in rehabilitation.

**Are All Tasks Amenable to Mental Practice?**

A large body of knowledge supporting the use of mental practice to enhance skill acquisition comes from studies conducted in athletes and in healthy individuals. It is generally recognized that for tasks with a large cognitive component (eg, pegboard, card sorting), mental practice yields stronger effects (effect size=...
1.44) compared with motor tasks with an effect size of 0.43. The difficulty, however, is to determine the size of the cognitive component in any motor task. Moreover, the cognitive dimension of a task changes as the skill level of the performer changes; a novice may be thinking about how to do the skills, whereas an expert is concentrating on the strategy and tactics related to the performance of that skill. It also is believed that other factors such as the level of familiarity and task complexity interact to determine effects. For example, the use of motor imagery to train isometric voluntary contractions, which induced a substantial increase in maximal torque with the untrained (weak) abductor muscle of the fifth digit, had no beneficial effects on the strong elbow flexor muscles. Such findings indicate that even a task with a low cognitive component (eg, learning to contract a muscle maximally) can benefit from mental imagery training in the early stage of strength training that involves a neural component (eg, learning to contract a muscle maximally requires spatial recruitment of existing motor units). Thus, benefits are to be expected with a motor task when mental practice targets motor planning and preparation components (eg, sequencing of complex foot movements, coordination of movements from different body parts). Interestingly, meta-analyses revealed that positive effects for highly cognitive tasks (eg, card sorting, peg-board) were associated with very few trials and minutes per session, whereas for motor tasks, positive effects were obtained with longer sessions and more repetitions per session.

**What Imagery Perspective Should Be Used?**

One issue in mental practice is the selection of perspective: should an internal perspective or an external perspective be used? Because the terminology with visual (external) and kinesthetic (internal) imagery versus the type of perspective sometimes is confusing, in the present article external perspective refers to a perspective that involves primarily a visual representation (third person) of the motor task, whereas internal perspective entails, in addition to the kinesthetic sensations, a visual representation (from the inside: first person) of the simulated movements, thus both visual and kinesthetic cues.

Therefore, should the patient be instructed to imagine another person walking or to imagine himself or herself walking from the inside? Behavioral, neurophysiological, and brain imaging studies have shown that, compared with the third-person perspective, the first-person perspective shares more physiological characteristics with those observed during the execution of movement, and thus movement imagery in the first-person perspective is closer to the real execution of movement. For that reason, the challenge with motor imagery training of gait is to ascertain that the patient really is imagining the task in the first-person perspective and focusing his or her attention on both visual and kinesthetic cues to promote activation of neural networks associated with motor imagery of gait. Consequently, instructions should direct the patient to focus on both visual and kinesthetic components seen and felt from the inside. Because the vividness of visual imagery usually is better than that of kinesthetic imagery, concentrating on visual cues may be easier initially, but both should be encouraged. For instance, patients should envision walking within an environment (eg, imagine a path’s width, the size or the position of the obstacles) and the displacement of their limbs (eg, see the top of the feet, the inside of the swinging arms) and re-create the sensations associated with the task (eg, feeling the push-off, the effort to increase the step height or length). These cues should be introduced gradually and progress according to each individual’s needs and ability. In addition, therapists should inquire about what patients see and feel during the imagination phase to ascertain that they are engaged in first-person motor imagery. Checking periodically with mental chronometry or autonomic responses is another way to monitor whether the patient really is engaged in imagining a given task. These procedures should not only assist in the development of vivid images but also help control the mental representation of the motor tasks throughout the training session.

**How Should We Position the Patient During Imagery Training?**

Another consideration during motor imagery training is the patient’s posture because internal representation of a movement implies a motor plan based on a body-centered frame of reference, which depends on visual-kinesthetic inputs. Results from fMRI and TMS studies have shown that when the position of the imagined hand is congruent with the actual hand position, higher levels of cortical facilitation and brain activations are recorded implying that motor imagery generates motor plans that depend on the current configuration of the limbs. However, a recent study that examined the effects of hand posture on mental rotation of hands and feet showed that mental rotation of hands but not of feet was influenced by changes in hand posture. Their findings suggest that postural information coming from the body may influence mental rotation of body parts according to specific somatotopic rules. To date, no study has investigated whether body orientation (sitting or standing versus lying supine) influences cortical activation during the imagining of hand or foot movements. However, during imagery training in a clinical setting, there are advantages
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to placing the patient in a position similar to that used during physical execution of the task. For instance, for a task such as rising to a standing position or reaching forward, a sitting position will provide the visual and kinesthetic cues that will help develop a mental representation of the task from a first-person perspective.47,48 Moreover, assuming the same position during both conditions (simulation and execution) is more practical when series of mental repetitions are combined with physical repetitions.47,48 Lastly, to promote the concentration and relaxation that facilitate motor imagery vividness,63 care should be taken to provide seated individuals with back and head support during the simulation condition.

Is It Important to Combine Mental Practice and Physical Practice, and, If So, How Should It Be Done?

Another question concerns optimal conditions for motor imagery training. Although mental rehearsal alone can promote brain reorganization38,39,40 and have a priming effect on subsequent physical training,40 the number of sessions and repetitions required to observe motor improvement may depend on the type and complexity of the task.39,40,76,77 Evidence of improved motor performance was observed after 1,500 mental rehearsals of a foot movement sequence over a 5-day training period.59 In another study, young individuals who were healthy needed 120 mental repetitions over a single training session before a significant improvement of a complex manipulative skill was observed.76 A third study involving complex finger movement sequences showed that subjects who only trained mentally for 2 hours a day had reached after 5 days the level of performance attained after 3 days of physical practice.40

Most interesting is the fact that on the fifth day, the group who had trained mentally needed only 2 hours of physical practice to reach a level of performance similar to that of the subjects who had trained physically 2 hours a day for 5 days.40 If findings can be extended to locomotor tasks in people with physical disabilities, it could mean that patients who mentally rehearse walking before they actually can stand and walk would show improvement faster once they start walking than those who did not rehearse mentally.

Although motor improvement can be obtained with motor imagery alone, better results are obtained when combining physical and mental rehearsals of a task.2,42,62 We also must keep in mind that mental practice is an adjunct to habitual therapy and that mental rehearsal of a task does not replace physical practice of the same task.2,62,63 Therefore, the choice of strategy for combining mental and physical repetitions is paramount. We know that the temporal features of imagined walking are less variable from trial to trial when each mental rehearsal is separated by a physical rehearsal, suggesting that the afferent information is helpful for consistent reproduction of the next imagined movement.9 Only a few clinical studies46–48,54 have provided details about the training procedures and controlled for the number of physical and mental rehearsals. To date in the clinical setting, good adherence and learning effects46–48,54 have been reported with training paradigms combining physical execution trials and mental rehearsal trials in proportions ranging from 1 physical execution and 5 mental rehearsals to 1 physical execution and 10 mental rehearsals for retraining rising and sitting down in people following stroke. Because mental rehearsals at the outset of training demand much attention and concentration, it is suggested to gradually increase the number of mental repetitions46,47,54 between physical repetitions. Including one physical execution between bouts of mental repetitions has been found to help in maintaining the kinesthetic sensations of the task.46,47,62

Teaching Motor Imagery

Findings from studies carried out in athletes62–64,78 can provide some guidelines for teaching imagery in clinical settings. Because motor imagery is a complex, multidimensional process, it is important to provide imagery instructions with sufficient details to ensure that the individual is imagining the task in the desired manner (eg, with vividness and perspective). It must be clear whether the entire task is to be imagined or just specific parts, and for more-complex tasks, the proper sequence of movements should be taught. Thus, verbal instructions are very important, and it is essential to establish a dialogue between the teacher and the learner, especially in the beginning, to make sure that the instructions are well understood. It also is suggested that people who have low imagery ability or who are not familiar with motor imagery start by imagining skill tasks that they already do well.63 Best outcomes are expected when the imagery includes a positive or successful performance.78

Conclusions

Several lines of evidence point to the beneficial effects of mental practice for retraining locomotor skills. However, further clinical studies with strong designs and larger groups are needed to confirm and generalize the positive findings reported so far. Clinicians must be aware that good and bad imagers coexist after stroke,24 and thus it is imperative to evaluate motor imagery ability before introducing mental practice. Based on recent findings that mental representation of actions is highly modulated by imagery practice,57 patients who
initially demonstrate difficulty in generating mental representation of movements eventually may improve their motor imagery ability with repeated exposures. Virtual environments\(^7\) and observation of gait\(^7\) may provide the visual reinforcements necessary to promote the generation of proper mental images in poor imagers of walking or those who cannot yet walk.

The use of mental practice as an adjunct to physical practice in neurorehabilitation still is relatively new, and many questions remain regarding the optimization of training strategies. Should patients be lying down and relaxing while listening to prerecorded instruction tapes, or in contrast, should they be more actively engaged in their training? Should they learn to self-monitor their training and solve problems along the way?\(^6\)\(^,\)\(^7\)\(^,\)\(^8\)\(^,\)\(^9\)\(^,\)\(^10\) so that motor imagery eventually may improve movements eventually may improve their motor imagery ability with repeated exposures. Virtual environments\(^7\) and observation of gait\(^7\) may provide the visual reinforcements necessary to promote the generation of proper mental images in poor imagers of walking or those who cannot yet walk.

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Mental Practice for Relearning Locomotor Skills