Potential Role of Mental Practice Using Motor Imagery in Neurologic Rehabilitation

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For many patients with damage to the central nervous system (CNS), execution of motor tasks is very difficult, sometimes impossible, even after early participation in an active rehabilitation program. Several investigators have recently proposed that mental practice could be used by these patients as a therapeutic tool to improve their performance of motor functions, yet very little empirical work addresses this issue directly. This article discusses the rationale for investigating mental practice as a means of promoting motor recovery in patients with a neurologic disorder. We first present evidence supporting the existence of a similarity between executed and imagined actions using data from psychophysical, neurophysiologic, and brain imaging studies. This parallel is then extended to the repetition of movements during physical and mental practice of a motor skill. Finally, a new model is proposed to emphasize the key role of motor imagery as an essential process of mental practice, and also to stimulate additional research on this type of training in the rehabilitation of patients with motor impairments of cerebral origin.

Key Words: Motor skills; Nervous system disorders; Rehabilitation.

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Humans have the ability to generate mental correlations of perceptual and motor events without any triggering external stimulus, a function known as imagery. Studies of this process come from different areas of research such as sport psychology, cognitive psychology, and more recently, cognitive neuroscience. Each area has its own vocabulary, which can sometimes create confusion. A definition of the different concepts of imagery used in this article is hereby proposed. Mental imagery refers to the active process by which humans relive sensations with or without external stimuli. This cognitive operation can be performed in different modalities such as visual, auditory, tactile, kinesthetic, olfactory, gustatory, or any combination of these senses. Movement imagery is a general term that describes the process of imaging the movement of an object or a person. For instance, mental rotation is a form of movement imagery in which subjects have to rotate a geometric figure mentally in order to identify its shape. When the human body is involved, however, researchers have preferred to use the term motor imagery, which corresponds to an active process during which the representation of a specific action is internally reproduced within working memory without any motor output. Finally, the concept of kinesthetic imagery has also been proposed, especially in the context of athletic training, to emphasize the importance of the kinesthetic component of a movement over its visual aspect.

In contrast to the imagery process per se, mental practice, also called mental or symbolic rehearsal, consists of a training method by which the internal reproduction of a given motor act is repeated extensively with the intention of improving performance. To avoid confusion with motor imagery, we believe it is important to reiterate the distinction drawn by Ravey between the process of imagining a movement once or a few times (ie, motor imagery) and the act of repeating the imagined movements several times with the intention of learning a new ability or perfecting a known skill (ie, mental practice). Thus, motor imagery will refer to a specific cognitive operation, whereas mental practice will designate a training method that can use various cognitive processes, including motor imagery.

Several studies in sport psychology have shown that mental practice can be effective in optimizing the execution of movements in athletes and help novice learners in the incremental acquisition of new skilled behaviors. Moreover, in recent years, a growing body of research has shown that there exist psychophysical as well as physiologic similarities between physically executed and imagined movements. Based on such findings, many investigators have proposed use of mental practice in physical rehabilitation as a cost-efficient means to promote motor recovery after damage to the central nervous system (CNS). A review of the literature on mental practice reveals, however, that only a few modest attempts to apply mental practice in a rehabilitation context have been conducted to date. One possible reason for this lack of experimental evidence is that theoretical and practical guidelines as to how and when to implement mental practice in the physical rehabilitation of patients are still scarce. Moreover, the instruments used to measure improvement in performance might be insensitive to the type and the magnitude of changes that can be observed with mental practice. In this study, the rationale behind the clinical use of mental practice is examined by outlining the importance of motor imagery in this mode of training.
SUMMARY OF PERTINENT RESEARCH

Motor Imagery

Over the past 20 years, the number of experiments investigating the psychophysical and physiologic correlates of motor imagery has increased considerably. In general, study results indicate that the timing of movements, either performed physically or imagined, is subject to common laws and principles. Indeed, it has been shown that Fitts’s law, which states that more difficult movements take more time to produce physically than do easier ones, applies also to imagined movements.9 This conclusion is based on the findings of a series of experiments in normal control subjects that examined the temporal relationship between the execution of a motor task and the imagination of the same action (ie, mental chronometry).6,15-17 The temporal congruence between imagined and executed movements has also been observed after damage to the brain. Decety and Boisson18 found that patients with unilateral cerebral lesions took more time to imagine a movement with their affected limb than with their nonaffected limb. On the other hand, patients with a paraplegia or a tetraplegia caused by lesions of the spinal cord produced imagined movement times comparable with those of healthy subjects,19 hence supporting the idea that motor imagery is a process that depends on the integrity of motor-related structures restricted to the cerebrum. These results indicate that patients with a brain lesion affecting the motor system are likely to be able to imagine movements but that their performance, either physical or imagined, is affected similarly. Altogether, these findings support the idea that the structures or systems mediating the mental simulation and the physical execution of actions are alike.

Additional confirmation of functional similarity between executed and imagined movements comes from numerous studies that have shown an increase in the heart and respiration rates of subjects engaged in the motor imagery of effortful actions.7,19-21 In general, these studies have shown that changes in subjects’ autonomic reactions are larger than what would be expected, considering that no actual movement is produced. Based on such findings, Decety22,23 has proposed that during imagined activities, a significant portion of the observed increase in autonomic response is of central origin, as though the mind deludes the body into believing that some movements are being executed.

More evidence of the correspondence between imagined and executed movements is also provided through functional brain imaging studies with healthy subjects. At first, the findings from a series of experiments with single photon emission computed tomography showed that the neural substrate involved in the cerebral structures were different from those implicated executing the same movements.24-26 However, the advent of other brain mapping techniques such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and magnetoencephalography (MEG) allowed a more precise anatomic localization of the cerebral structures implicated in performing imagined and executed movements of the upper limb. The results of these studies are summarized in table 1.

Altogether, these findings suggest that the supplementary motor area (SMA), cerebellum, as well as the premotor, cingulate, superior and inferior parietal, and sensorimotor and primary motor cortices are often found to be involved in both the execution and the imagination of upper limb movements. Recent data from a PET study in our laboratory have confirmed this anatomic correspondence and extended these results to a motor learning paradigm involving the acquisition of a sequence of movements of the left foot in healthy subjects (Lafleur et al, unpublished observations). Indeed, changes in regional cerebral blood flow (rCBF) associated with physical execution of the sequence early in the learning process were observed bilaterally in the dorsolateral premotor cortex and cerebellum, as well as in the left inferior and superior parietal lobules and in the right SMA. After a 1-hour training period, however, these motor regions were no longer significantly activated, suggesting that they are critical for establishing the motor learning paradigm involving the acquisition of a sequence of movements of the foot. In contrast, after practice, an increased level of activity was seen bilaterally in the rectus gyrus and striatum, as well as in the left anterior cingulate and inferior parietal lobule, suggesting that these structures allow the development of a long-lasting representation of the sequence. Most important, a similar pattern of dynamic changes was observed in the motor imagery conditions in both learning phases, ie, before and after intensive physical practice. These data suggest that the plasticity that occurs during the incremental acquisition of a motor sequence can also be observed during the imagination of this skilled behavior. Finally, no significant change in blood flow was observed in the primary motor area during the imagined conditions, which is probably because of the limited spatial resolution of the brain mapping technique used, as pointed out by other investigators.27,28

Although results from brain imaging experiments generally suggest that executed and imagined movements share a common neural substrate, 2 major issues remain unresolved. First, subtle differences in the site of activation between these conditions have been reported within the SMA and cerebellum.29-32 Although still conjecture, such anatomic distinctions might be related to the voluntary inhibition necessary to prevent muscle contraction and movement during motor imagery.33,34 Second, the role of the primary motor cortex during mental simulation of movement continues to nurture debate.35 Before 1995, none of the published functional brain imaging studies had reported a significant activation of this area during motor imagery. For example, as in our own study, investigators who used PET failed to show a significant change of rCBF in the primary sensorimotor cortex while subjects were scanned in an imagined condition.28,31,36,37 In contrast, recent experiments using imaging techniques that provide better temporal or spatial resolution, such as EEG,38 MEG,39-40 and fMRI,41-43 have shown that the primary motor cortex is activated during motor imagery, albeit to a lesser degree than when movements are actually performed. Thus, the role of this structure in the simulation of movement is a strong argument in favor of a functional similarity between imagined and executed movements, although its precise contribution in motor imagery still needs to be clarified.

A final source of evidence supporting the notion of congruence between imagined and physically performed activities is provided by experiments measuring changes in the excitability of motoneurons in the nervous system. Several researchers have used transcranial magnetic stimulation to apply a focused magnetic field to the motor cortex of subjects while recording motor-evoked potentials in the contralateral muscles. The goals of these studies were to determine whether a similar facilitation effect occurs during motor imagery and the physical execution of movements, as well as to investigate whether the temporal pattern of cortical activation coincided in both cases. The results have shown that motor imagery elicits an increase in cortical excitability when compared with a rest control condition,8,34,44-48 and that the dynamic pattern of cortical activation during imagined movements is similar to that observed when actual activities are performed.8,45-48
by methodologic biases. For instance, in some studies, the level of activity in the spinal reflex pathway remains unchanged when subjects are engaged in motor imagery, implying that subjects moved or contracted their muscle. These small movements or muscle contractions have previously been shown to produce increases in the level of spinal reflex activity. Other factors that could modulate spinal excitability during motor imagery include the level of proficiency in the task, the imagery instructions given to the subjects, as well as the imagery abilities of subjects. In contrast, the second and most prominent pattern of results reveals that the level of activity in the spinal reflex pathway remains unchanged when subjects are engaged in motor imagery, suggesting that this type of process does not send descending volleys to the spinal cord, as actual movements do. Therefore, although imagined activities produce a pattern of dynamic changes in the excitability of motoneurons resembling that of executed movements, this similarity seems restricted to the cerebral level.

### Mental Practice

The idea that mental practice can enhance the learning of motor skills is not new. Using measures of spatial accuracy of movements and execution time, several studies in the sport psychology literature have previously shown that mental practice can improve the performance of motor skill behaviors. These studies have generally shown that volunteers who train mentally on a specific task usually display less improvement than those who train physically, although mental practice leads to superior increases in performance compared with a non-practice condition.

Further evidence that physical practice and mental practice share several attributes was recently provided by Yaguez et al. These researchers have shown that a 10-minute period of mental practice was sufficient to improve the performance of a task in which healthy subjects were required to draw ideograms of different sizes. As opposed to most studies of mental practice that have used speed and accuracy as dependant measures, the improvement reported by Yaguez involved the dynamics of movement. According to these investigators, the changes in performance were unlikely to be open to introspection or verbal analysis, which suggests that part of the learning observed following mental practice of a graphomotor task can be implicit.
in nature. Such findings underline the importance of having instruments that can detect performance changes across several outcome measures.

Gains in isometric muscular strength have also been observed after mental practice. For example, Cornwall et al\(^6\) have found that subjects who trained mentally to contract their quadriceps showed a greater increase in isometric muscle strength than volunteers in a no-practice control group. Similarly, Yue and Cole\(^1\) have reported gains in isometric strength after mental practice. They found that after 4 weeks of training, subjects in the physical, mental, and no-practice groups increased the strength of the abductor muscle of the fifth finger by 30%, 22%, and 3.7%, respectively, although no muscle hypertrophy was observed. These investigators\(^5\) interpreted their results according to the Neural Training Hypothesis,\(^6\) which stipulates that in the first phase of muscle training, the increases in strength are caused by adaptive changes in central processes rather than by an hypertrophy of the muscles. They suggested that the gains observed after mental practice could be attributable to neural changes at the programming and planning levels of the motor system.\(^8\) More recently, however, another study conducted by Herbert et al\(^6\) failed to replicate these results and found that, compared with physical practice, mental practice did not produce any increase in voluntary isometric strength of the elbow flexor. Moreover, the Neural Training Hypothesis was tested in this experiment by measuring maximal voluntary contraction with the twitch interpolation technique before and after training. The authors\(^6\) found that neither physical practice nor mental practice increased voluntary activation of the muscles involved. It was pointed out, however, that maximal voluntary activation of the elbow flexor was already very high in the subjects, leaving little room for improvement. Thus, Herbert\(^6\) proposed that mental practice could produce more significant effects on muscles that exhibit low initial levels of voluntary contraction. This hypothesis remains to be confirmed if the neural training explanation is to gain further support.

Although the behavioral effects of mental practice on the learning of a motor skill have been investigated using different types of paradigms, only a few studies have examined physiologic correlates of the changes in performance. In 1 of these studies, Roure et al\(^6\) used autonomic measures (eg, skin potential and resistance, heart rate, respiratory frequency) to rate the quality of the imagery that subjects engaged in during mental practice. They reported a positive correlation between the performance gain on a volleyball task after mental practice and the rating of the level of imagery intensity.\(^6\) This result suggests that better imagers (ie, individuals who produced autonomic nervous system responses on the greater number of trials in the imagined condition) improved more on the task than other subjects, supporting the idea that the better the imagery, the better the outcome of mental practice.

Other evidence in support of the action of mental practice on motor processes comes from a recent study in healthy subjects that examined the changes in functional reorganization of the brain after this type of rehearsal. Using transcranial magnetic stimulation, Pascual-Leone et al\(^6\) have shown modulations in the motor cortical areas involved in a 1-handed piano exercise during both physical and mental practice of this skill. They showed that the size of the contralateral cortical output map for the long finger flexor and extensor muscles increased progressively each day, as subjects practiced this task over a period of 5 days. The increase in size of the representation was equivalent in both physical and mental training conditions. Furthermore, both conditions produced behavioral improvements, although subjects in the physical practice group displayed greater learning after training. The level of performance in the mental practice condition after 5 days of training was equivalent to that of the physical practice condition after only 3 days. These investigators showed, however, that after adding only 1 physical training session after the 5 days of mental practice, subjects who practiced the task mentally reached the same level of performance as those who were in the physical training group. Altogether, these findings suggest that mental training produces representational changes in the brain comparable with those yielded by physical practice, and that part of the behavioral improvement seen in the mental practice condition may be latent, awaiting to be expressed after minimal physical practice. Mental practice could thus have a preparatory effect on the task, which increases the efficiency of subsequent physical training.\(^6\)

In fact, different combinations of physical and mental practice have often been shown to be more efficient than either form of training alone.\(^4\) This pattern of results has recently been confirmed in our laboratory using a motor sequence learning task involving the lower limb (Jackson et al, unpublished observations). Our results showed a superior effect of a combined practice condition over either mental practice or physical practice conditions alone, even though the amount of physical training in the combined condition was minimal (ie, 10:1 ratio) compared with that of mental practice. This suggests that the effect of mental practice is greater when physical practice is added, even in small amounts, during long-term training of a motor skill.

In summary, results from different lines of research support the notion that mental practice, similar to physical practice, can improve the performance of a motor skill and that this increase in performance is associated with physiologic and plastic changes at the cerebral level. However, controversies still persist regarding the efficiency of this training technique, because many of the variables under study, such as the nature of the motor task, the amount of practice, and the learning stage at which mental practice is introduced, are often not taken into account when interpreting the results (see Hall et al\(^6\) and Janssen and Sheikh\(^6\) for critical reviews of these methodologic factors).

**Theories of Mental Practice**

Many theories have been proposed to explain the mechanisms by which mental practice acts to increase performance in motor learning.\(^6\) Yet, few have been experimentally tested and none offers a satisfactory explanation for the existing findings.\(^5\) For example, Sackett\(^7\) proposed the symbolic learning theory, which states that mental practice facilitates motor performance by allowing subjects to rehearse the cognitive components of a task. This theory implies that movements are symbolically coded in the CNS, making them easier to execute.\(^6\) The results of several experiments with mental practice are consistent with this theory because most meta-analyses of the phenomenon report greater effect sizes for tasks that include a strong cognitive content.\(^4\) The theory, however, does not explain other findings such as the increase in muscular strength reported after mental practice of isometric contractions.\(^1\) Indeed, the “cognitive demands” necessary to imagine this type of task are less complex than those required during the performance of other motor acts like producing a sequence of movements or walking around obstacles.

In contrast with the symbolic learning theory, the psychoneuromuscular theory is more compatible with results obtained using tasks that are more “purely” motor. The latter theory proposes that micronerve impulses are propagated to target muscles when a subject engages in the mental practice of a
movement, hence facilitating future performance by priming specific “mental nodes” or “patterns of movement” necessary to execute a motor task. Evidence in support of this theory comes from a study by Jacobson in which he recorded an increase in intramuscular activity while subjects were imagining movements. However, Feltz and Landers raised the possibility that such increase in muscular activity during mental practice is not specific to the muscle groups involved in the execution of the movement. In fact, in a study in which the electromyographic activity of several muscle groups was monitored, increases were found not only in the target muscles but also in nonrelated muscle groups. Such results are probably responsible for the decrease in popularity of the psychoneuromuscular theory.

A third theory about the effects of mental practice in motor learning comes from Paivio, who suggested that mental practice enhances performance by acting on both the motivational and cognitive components of an activity at either general (eg, the degree of physiologic arousal of an individual) or specific levels (eg, the actual practice of a motor task using motor imagery). Van Leeuwen and Inglis have recently modified this theory from a neurologic rehabilitation perspective. They correctly argue that a large part of the preoccupation in rehabilitation is given to the physical components of the training, often neglecting the patients’ motivational conditions. According to this view, mental practice would help patients focus on specific goals and could contribute to a reduction of the depressive state frequently observed in neurologic disorders. In addition, at the cognitive level, it is argued that use of mental practice would improve patients’ ability to acquire specific skills and to promote the elaboration of strategies that could eventually be generalized outside the clinic. This theory, however, fails to identify the key role of 1 specific type of imagery (ie, motor imagery) that can be used during mental practice of a motor skill.

Training in Neurologic Rehabilitation: A New Conceptualization of Mental Practice

As evident from the brief description of the theories of mental practice presented above, most of them have focused predominantly on either the motor, cognitive, or motivational processes underlying the changes in performance over time. Although the contribution of each of these components to the learning of skilled behaviors through mental practice is undeniable, each theory taken separately cannot explain all of the inconsistencies encountered between studies in this area of research. Furthermore, it is often difficult to tease these components out and to measure their distinct contribution, as they interact during the acquisition process. Therefore, this distinction along the motor and cognitive axes is difficult to test experimentally and not easily applicable to clinical issues.

An alternative framework is proposed here in an attempt to elaborate a unified and practical model of the potential therapeutic effects of mental practice relative to other forms of training used in neurologic rehabilitation. This new model is based on some historical and contemporary theories of mental practice, as well as notions taken from research in motor imagery and motor skill learning (fig 1).

The present model acknowledges that motor, cognitive, and psychologic factors contribute to the outcome of different forms of practice, including mental practice. However, we propose that up to 3 distinct levels of learning processes can contribute and interact with one another during practice of an activity, depending on the form of training used: (1) declarative knowledge, (2) nonconscious processes, and (3) physical execution. In this model, declarative knowledge refers to the information about the skill that subjects need to know explicitly before practicing a given motor task, such as the limbs involved in producing the movement or the sequence and direction of the movements to be performed. The nonconscious processes correspond to aspects of the skill not directly accessible to a verbal description by an individual, such as the timing between a cue and a specific motor program, the coarticulation of small segments of movements into a unified sequence, and the rapid and sequential activation or inhibition of different muscle groups. Finally, the physical execution is the musculoskeletal activity necessary to carry out the intended action. As shown in figure 1, different types of training approaches can use either 1, 2, or all 3 of these levels of processing. The outcome of each training method can then be measured either...
through improvement in performance, changes in cerebral organization, or an increase in the subjects’ level of arousal and motivation.

According to this model, the outcome of training would be optimal during physical practice because all 3 levels of processing are usually implicated and interacting with one another. The involvement of each of these levels of processing can also vary during the course of practice. For example, the use of declarative knowledge known by subjects can be more important at the beginning of training than when the task is well learned. Mental practice with motor imagery has also been shown to be beneficial for the learning of several motor tasks. In this form of practice, the mechanism underlying the improvement also depends on the interaction between the declarative knowledge and the nonconscious processes involved in acquiring the skill. Contrary to the condition in which a motor task can be learned implicitly with physical practice, mental practice with motor imagery requires that subjects have all the necessary declarative knowledge about the different components of the task before practicing. However, as with physical practice, the rehearsing of the task with motor imagery can also give access to the nonconscious processes involved in learning the skilled behavior.

Indeed, the findings presented earlier on the similarity of the circuitry involved in imagining and executing movements suggest that the neuronal network implicated in the nonconscious aspects of a task can be primed with mental practice. Our model predicts that internally driven images, which promote the kinesthetic “feeling” of movements, would best activate the different nonconscious processes involved during motor task training. Indeed, there is some evidence, although still controversial, that motor imagery performed using a first-person perspective (ie, internally) yields better improvement after mental practice than when performed in the third-person perspective. Thus, mental practice with motor imagery can be conceptualized as an “explicit access” to the otherwise nonconscious learning processes involved in the task. However, the absence of direct feedback from the execution system makes mental practice a less potent training method than physical practice.

Finally, nonspecific mental practice (also called mental preparation) is a more general type of practice that comprises many different approaches aimed at improving motor performance, such as psyching-up strategies and relaxation. This holistic way of rehearsing often involves an emotional content aimed at winning or optimizing the execution of a certain skill. It is thought to be less effective than physical and mental practice with motor imagery because it does not tap into any of the nonconscious processes of a skill because those involved remain accessible to verbal analysis. Such a form of practice can nevertheless lead to some improvement in performance, probably by acting on general processes such as the development of learning strategies applicable to any movement and the enhancement of motivation.

We believe that this new conceptualization of motor practice and skill learning is not only interesting because it helps us understand most of the results in the literature, but also because it provides practical guidelines for the implementation of this training technique at different stages of the rehabilitation process.

**Mental Practice in Neurologic Rehabilitation**

As presented earlier, there is now sufficient evidence to foster the idea that mental practice can improve the learning of motor skill in healthy individuals. Furthermore, the model presented above underlines the importance of motor imagery as an essential component of mental practice.

We now discuss some theoretical and practical issues related to the application of this new approach in neurologic rehabilitation.

First and foremost, it is important to note that the superiority of physical practice over mental practice in several studies of motor skill learning suggests that mental practice should be considered as a complement to physical rehabilitation and not as an alternative method. Second, as proposed in our model, the capacity to generate imagined movements is necessary for mental practice to be most effective. In fact, recent evidence suggests that lesions restricted to the parietal lobes can impair motor imagery, implying that some neurologic patients may not benefit from mental practice. Other results supporting this notion come from a recent study by Yaguez et al who found that some disorders of the basal ganglia influence use of mental practice. These authors compared the ability to learn graphomotor trajectories in a group of patients with Parkinson’s disease with that of a group of patients with Huntington’s disease after a 10-minute training period using motor imagery. Their results showed that mental practice helped the performance of patients with Huntington’s but not that of patients with Parkinson’s. It was further shown that Parkinson’s patients did not learn the task with physical practice, nor did they perform well on measures of visual imagery. In the Huntington’s group, a negative correlation was also found between the degree of atrophy in the caudate nucleus and performance on the visual imagery tasks, suggesting that atrophy of the caudate nucleus could specifically affect visual imagery, without hampering motor imagery. Thus, these findings suggest that not only lesions to the cortex, but also damage to subcortical structures may reduce patients’ ability to produce the appropriate imagery process. They also stress the importance of assessing the motor imagery ability of patients before considering using mental practice as a therapeutic means.

To assess motor imagery abilities, several clinical clues based on psychophysical, physiologic, and neuroanatomic correlates of motor imagery can be obtained. In the clinical setting, as noted previously, it has been shown that patients with a stroke are slower when they imagine performing movements with their affected limb than with the nonaffected limb. Thus, the manifestation of the patient’s motor deficit in the timing of the imagined task would be a good indicator that motor imagery is being performed adequately, ie, using a motor-related circuitry that is analogous to that used during physical execution of the task. Another clue suggesting that patients have some control over the imagery process is that the time taken to imagine a movement is similar from 1 trial to the next. Both of these chronometric measures are technically easy to obtain after appropriate instructions and could be used to evaluate motor imagery abilities in patients with cerebral damage.

Third, once the patients’ capacity to produce motor imagery is assessed, the focus can then be directed to the severity of the motor impairment, and the moment at which mental practice should be introduced in the treatment. In cases where the neurologic condition does not allow the patients to produce movements, the rehearsing of a skill with motor imagery is believed to help keep the motor program active, thus priming and facilitating the future execution of specific movements. At this stage of the rehabilitation process, mental practice is expected to act on the declarative knowledge and nonconscious levels of learning by improving, respectively, among other processes, the level of retention of a pattern of movements and the rehearsing of the neuronal network involved in the skill.
For patients with spared functions or for patients with partial recovery who need to learn new skills (eg, walking with a cane), the addition of physical practice to mental practice is thought to promote learning by further reinforcing processes at the nonconscious level. Feedback obtained from executing targeted movements during physical rehabilitation would help produce more realistic and efficient motor imagery, hence increasing the potential of mental practice and possibly accelerating the rate of recovery. Mental practice could thus be used to multiply the number of repetitions of a movement at the cerebral level,74 without adding to the physical demands of training. This method might also be useful after patient discharge from the rehabilitation center, in order to maintain gains acquired with training, and possibly to lead to additional improvement. Beneficial effects of extensive practice using various techniques have been reported in chronic stroke patients.90,91 The combination of mental practice with such techniques could extend the time spent practicing tasks, and therefore the magnitude of the improvement in performance.

CONCLUSION

The therapeutic potential of mental practice with motor imagery is more than a leap of faith and can be expressed as a reasonable working hypothesis that needs to be tested. More specifically, it will be useful to elaborate guidelines to determine the best timing to introduce mental practice in the rehabilitation process. Additional important clinical issues that await further support include the selection of patients most likely to benefit from mental practice, the effects of cognitive deficits after brain lesion on the ability to imagine movements, the choice of instruments able to detect small changes in performance, as well as the use of a technologic medium such as virtual reality in mental practice. We believe that the main question is no longer whether mental practice can help in the rehabilitation of neurologic patients,2 but rather, what is the best way to implement this cost-efficient technique into current practice.

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