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The Efficacy of Combined Physical and Mental Practice in the Learning of a Foot-Sequence Task after Stroke: A Case Report

Philip L. Jackson, Julien Doyon, Carol L. Richards, and Francine Malouin

Objective. *To investigate the effect of mental practice on the learning of a sequential task for the lower limb in a patient with a hemiparesis resulting from a stroke.* Design. *A single-case study.* Setting. *Research laboratory of a university-affiliated rehabilitation center.* Patient. *A right-handed 38-year-old man who had suffered a left hemorrhagic subcortical stroke 4 months prior.* Intervention. *The patient practiced a serial response time task with the lower limb in 3 distinct training phases over a period of 5 weeks: 2 weeks of physical practice, 1 week of combined physical and mental practice, and then 2 weeks of mental practice alone.* Main Outcome Measures. *Performance on the task measured through errors and response times. Imagery abilities measured through questionnaires.* Results. *The patient's average response time improved significantly during the 1st 5 days of physical practice (26%) but then failed to show further improvement during the following week of physical practice. The combination of mental and physical practice during the 3rd week yielded additional improvement (10.3%), whereas the following 2 weeks of mental practice resulted in a marginal increase in performance (2.2%).* Conclusion. *The findings show that mental practice, when combined with physical practice, can improve the performance of a sequential motor skill in people who had a stroke, and suggest that mental practice could play a role in the retention of newly acquired abilities.*

Key Words: *Motor skill—Learning—Psychomotor performance—Rehabilitation—Stroke—Lower limb.*

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Mental practice (MP) with motor imagery (MI), or the symbolic rehearsal of a physical activity in the absence of gross movement,[1] has been shown to improve the performance of different motor skills. Several meta-analyses have been conducted and attest to the potential of MP in skill learning, although the general consensus is that MP with MI does not surpass physical practice but is often found to be superior to no practice at all.[2,3] There is now ample evidence from psychophysical, neurophysiologic, and brain-imaging studies supporting the similarity between executed and imagined actions.[4] Such a parallel has also been shown to extend to the repetition of movements during physical and mental practice of motor skills in healthy individuals.[5,6] This progressive understanding of the mechanisms underlying performance gained following mental practice has led many researchers during the past 50 years to propose the use of this training technique in physical rehabilitation to help the recovery of patients with motor deficits.[6-8] To date, only a few attempts to test this training method empirically in a clinical setting have been published.[9-12] The results from these studies suggest that mental practice can be used with good results for training the upper extremity after stroke. Surprisingly, however, none has looked at the effects of mental practice for the learning of motor skills involving the lower extremities in persons after a stroke. Even though the recovery of lower-limb function is often faster and appears more complete than that of upper limbs, retraining of mobility and locomotor-related tasks represent a large portion of the rehabilitation program. Exercises that involve the lower limbs are often physically more demanding than, for instance, manipulation tasks for the upper limbs. Patients could thus benefit from mental practice, especially in the early phase of rehabilitation, to increase the training load without adding substantial physical effort.

The aim of the present case study was thus to assess the effect and also the specificity of mental practice with motor imagery in the training of a sequential motor skill of the lower limb in a person who had suffered a stroke. The study was designed to measure improvement in performance over 3 consecutive training regimes: physical training, combined physical and mental practice, and mental practice alone. The foot-sequence task (FST) is based on the serial reaction time paradigm that has been used extensively to study motor skill learning.[6,13] The FST provides precise measures of motor learning for the lower limb and has previously been used to study cerebral reorganization in relation to motor imagery.[6,13] Our strategy was to start with a controlled task to measure objectively the impact of mental practice. The fact that only single-joint movements are necessary to execute the FST reduces the number of variables (degrees of freedom) that have to be taken into account to explain how the task is learned. Moreover, the task's simplicity makes it easier to use by people with motor deficits than a task involving whole limbs and multiple joint movements. It is also easy to imagine and can thus be practiced either physically, mentally, or both. The design used represents, on a smaller scale, one possible way of introducing mental practice during rehabilitation: patients that begin with physical practice of a skill can first develop a good motor representation of the skill. Adding mental practice then yields additional repetitions without physically fatiguing the patient. Finally, because the type of mental practice favored in this design does not require specific apparatus, patients can use it after discharge from the rehabilitation center.

METHODS

A research therapist was in charge of screening the patients to meet the following selection criteria. Inclusion criteria: having suffered from a unilateral cerebrovascular accident, more than 3 months prior, resulting in a hemiparesis, obtaining a score of at least stage 4 for the paretic foot on the Chedoke-McMaster Stroke Assessment Scale, and right handedness. Exclusion criteria: other major medical problems (e.g., heart condition, cancer), neurological (e.g., Parkinson's disease) and psychological disorders (e.g., depression), uncorrected hearing impairments, musculoskeletal disorders of the lower limbs, and severe cognitive deficits (e.g., amnesia, aphasia).

Subject

The patient was a 38-year-old right-handed man who suffered a stroke 4 months earlier. The patient agreed to participate and signed an informed consent form approved by the Quebec Rehabilitation Institute's ethics committee. Magnetic resonance imaging performed on the day of his stroke displayed a 1 to 2 cm hemorrhage-related lesion extending from the left cerebral peduncle to the left pulvinar of the thalamus. The patient initially presented with a severe hemiparesis of his right side, with his upper limb significantly more affected than his lower limb. He also had hypoesthesia of his right side, which gradually diminished during the following weeks, but did not completely resolve before the start of this study. There was no evidence, however, that these symptoms changed during the course of the study. Two weeks prior to testing, the patient reached 56/56 on the Berg Balance Scale and 33/34 on the lower-limb motor subscale of the Fugl-Meyer Assessment. He had reached the highest level (stage 7) of motor recovery of the foot on the Chedoke-McMaster Stroke Assessment Scale.[14] Results from 2 routine neuropsychological exams showed persisting reduction in psychomotor processing, minor verbal learning difficulties and reduced verbal fluency about 1 month prior to this experiment.

Materials

The patient's motor imagery abilities were assessed with the Imaginary Tapping Test[6,13] and the Kinesthetic and Visual Imagery Questionnaire (KVIQ). The KVIQ, which includes a series of 10 gestures, is a modified version of the Movement Imagery Questionnaire[15] adapted for older patients and patients with motor deficits.[16,17] In this test, the patients rate their capacity to elicit mental images of the action on two 5-point scales (5 = high imagery; 1 = low imagery). One scale rates the clarity of the image (visual score: max 50), and the other rates the intensity at which they can feel themselves executing the movement (kinesthetic score: max 50). In the Imaginary Tapping Test, the patients are asked to execute and imagine tapping their feet on the floor at a comfortable pace, while counting the number of taps until the experimenter tells them to stop. Each trial is terminated after varying randomized intervals (10s, 25s, 45s). The number of taps produced should be similar in both

Experimental Design

	Phase 1 (2 weeks)										Phase 2 (1 week)					Phase 3 (2 weeks)
Session :	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Rep. PP :	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Rep. MP :											120	120	120	120		720

Rep. PP = number of repetitions of the sequence with Physical Practice of the task
Rep. MP = number of repetitions of the sequence using Mental Practice with Motor Imagery

Figure 1. Schematic representation of the experimental design showing, for each evaluation session, the number of repetitions of the sequence using either physical practice (PP) or mental practice (MP).

physical and imagined conditions and should correlate with increasing delays.[6,13]

Compliance with the mental practice schedule was monitored via a logbook. The apparatus on which the task was performed consisted of a rotating pedal mounted in a frame.[6] A potentiometer fixed on the pedal axis and connected to a relay box detected 3 different pedal angles (near maximum dorsiflexion, middle position, near maximum plantarflexion). A computer running Micro Experimental Lab (MEL) generated auditory stimuli through a speaker and registered the patient's response times (ms) and accuracy.

Table 1. Mental Practice with Motor Imagery Instructions

1. Assume a comfortable sitting or supine position.
2. Imagine the movements using the first-person perspective, as if you were actually executing them.
3. Avoid moving or contracting muscles from your leg and your head. Keep a relaxed position.
4. Remember to try seeing and feeling the movements as you do when you execute them.
5. Keep your eyes closed for the duration of the whole block of trials.
6. Keep track of the number of sequences imagined with your fingers, if necessary. You have to imagine that you are performing the sequence 6 times per block.
7. If you lose your concentration during a block, open your eyes, relax for a few moments, and then start over the same block.
8. Remember to imagine the sequences as quickly as possible, while making as few errors as possible.

Experimental Design and FST

The patient performed the task in a supine position. It consisted of executing, as quickly and accurately as possible, dorsiflexions in response to high-pitched sounds (2000 Hz), and plantarflexion in response to low-pitched sounds (100 Hz). The patient had to bring his foot back to a neutral middle position to trigger the next auditory stimulus. After familiarization (12 random trials), the patient was taught a specific sequence of 6 dorsi- and plantarflexions of the ankle (up-down-down-up-down-up). During the 1st 2 weeks of training (phase 1: see Figure 1), the patient participated in 10 practice sessions, each comprising 5 blocks of practice with the FST. Each block consisted of 6 repetitions of the known sequence of 6 elements (30 sequences per session). The patient subsequently took part in 5 physical training sessions over a 1-week period (phase 2), during which he had to complete 5 blocks of practice as described above. Moreover, between each of these sessions, the patient was asked to complete 2 mental practice periods on his own using mental practice with MI in a 1st-person perspective. During each mental practice period, the patient assumed a supine position and imagined the task for 10 separate blocks of trials following a set of instructions (see Table 1). He was also asked to register the time and duration of each training period, as well as to rate the vividness and kinesthetic sensation of the imagined movements in his logbook. Over the following 2 weeks (phase 3), the patient was asked to practice the foot sequence mentally on his own during 12 nonconsecutive practice sessions. Again, each of these sessions consisted of 10 blocks of motor imagery repetitions (60 sequences). Final assessment of the physical performance was done at the end of this 2-week period by asking the patient to execute 5 blocks of the sequence.

RESULTS AND DISCUSSION

The results obtained with the Imaginary Tapping Test (r = 0.99) demonstrated that the number of foot movements in the imagined and the executed conditions correlated with the increase in time intervals. However, the average imagined/executed time ratios for each foot was, respectively, 0.71 for the right (affected limb) and 0.73 for the left (non-affected limb), indicating that the patient made about 30% fewer taps during the imagined condition than during the executed condition with both limbs. In other words, the patient showed a bilateral slowing of foot tapping during the imagined condition. This finding is in line with observations from recent reports where patients with stroke demonstrated a bilateral slowing of movements in imagined conditions.[17,18] Interestingly, this bilateral slowing of the mentally imagined movement was associated with impaired working memory, suggesting a disturbance of the motor imagery process.[17] The results from the KVIQ showed a visual score of 20/50 and of 31/50 for the kinesthetic component, suggesting that the patient was consistently better at eliciting the kinesthetic than the visual aspect of the motor acts he was required to imagine. The relatively low score on the visual component of the KVIQ could be related to the slight decrease in visual attention reported in the initial neuropsychological testing, but specific testing of this function would be required to confirm this hypothesis. Future studies of mental practice with motor imagery in neurological patients should include measures of attention and working memory, as these cognitive functions seem related to the ability of patients to keep motor images within working memory.[17]

Inspection of the logbook data from phase 3 of training indicates that the patient practiced the sequence on 11 instead of 12 occasions as required, which indicates a compliance of 92%. The patient's ratings of the quality of the images and the intensity of the sensations imagined indicated that, overall, he did not have any difficulty in imagining the movements. Only once were those ratings below average (blurry images and vague sensation).

The main outcome measure on the FST, which consisted of the mean response time (reaction + movement times) in milliseconds to reach each of the target positions, was averaged over each session of 5 blocks (see Figure 2). The percentage of improvement over the baseline level of performance in the 1st session served as an indication of learning. The performance of the patient was also compared to that of a group of 9 healthy volunteers (aged between 45 and 53 years, mean: 50 years, SD: 2.45), who underwent the 1st phase of training in a previous experiment in our laboratory.[19] Inspection of the data from the 1st training phase suggests that the patient learned the foot sequence task across the 10 sessions (see Figure 2a). He reached, on average, a response time of 511 ms on the last training session of this phase, which corresponds to a 26% improvement in performance compared to his baseline performance on session 1. However, after 2 weeks of physical practice, the patient reached a level of performance that appeared asymptotic (i.e., showed no improvement in response time with further physical practice), but still much slower than that of older controls. The reduction in standard deviation (Figure 2b) suggests that performance was gradually more regular for this 1st phase. Once the mental practice was added, however, response times decreased gradually during the next phase, suggesting a direct relationship between the use of mental practice and the patient's improvement in performance. His performance continued to improve, from 507 to 455 milliseconds (an additional 10.3% improvement), during this 2nd phase. Moreover, the absence of variability in the standard deviations during the course of the same week (Figure 2b) suggests that mental practice helped the patient to be more consistent in his performance and suggests that timing between the cues and the corresponding movements was improved. The last phase of training only had a marginal effect on the patient's average response time, which dropped by 10 ms, hence representing an additional 2.2% improvement. Even though this hardly consists of an improvement, it nevertheless indicates that performance was maintained at the level reached during the previous training phase. The decreasing number of errors made on the FST across the experiment also attests to the global learning displayed by the patient (see Figure 2c). However, this last measure showed more fluctuation than the response times, and the addition of mental practice did not improve this aspect of performance, as the patient had already reached a minimal number of errors.

After the 3 phases of training, the patient remained about 9% slower than the average response time reported for the group of older normal volunteers after only the 1st 2 weeks of the physical training condition, which suggests that the patient had not yet improved to normal levels of

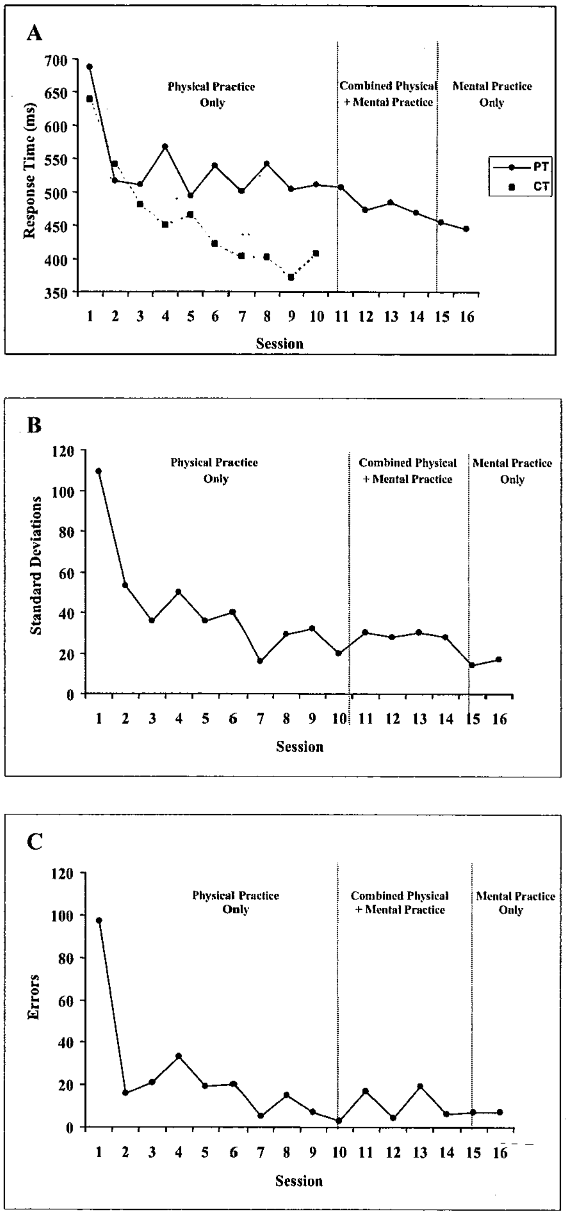

Figure 2. Graph illustrating the patient's A) average response time in milliseconds (continuous line, PT) compared to that of a group of healthy subjects (interrupted line, CT) B) average standard deviation taken from each block, and C) average number of errors, for each session, and during the 3 different training phases (Physical Practice Only, Combined Physical and Mental Practice, Mental Practice Only).

performance. Thus, our task provides very fine measures of motor improvement following mental practice in a patient who had well recovered according to routine clinical evaluations. This also suggests that mental practice with motor imagery is a low-cost method that can be used to enhance recovery beyond the level reached by conventional treatments. Note that the FST involves plantarflexions and dorsiflexions that are clearly distinct movements that have different functional roles. Future versions of this task could differentiate between these movements and thus measure their respective improvement.

The lack of additional improvement with physical practice observed after the 1st week of phase 1 could be related to the lack of complete sensory feedback from the foot of the patient. One of the deficits observed by the physical therapist that had only partly resolved after 4 months of recovery was a loss of proprioception, light touch, and temperature on the right side of the body, including the lower limb. Some studies have suggested that sensory deficits could interfere with motor skill learning.[20] Introduction of mental practice when performance seems to have reached an asymptote could compensate for this lack of feedback by providing another means to strengthen the motor program involved in the foot sequence task, for example, by reinforcing the nonconscious processing involved in the learning of this task, such as timing between the auditory cue and a specific movement.[4]

These findings open the door for another use of mental practice. It could indeed serve as a method to enhance the long-term retention of specific and recently acquired skills. The experimental design used in this study illustrates a feasible way of introducing mental practice to patients. Mental practice could be added to the traditional physical therapy treatments after a few weeks of training, and even earlier once the patients have a good representation of the movements to be rehearsed. Upon discharge from the rehabilitation center, the patient would be fully familiar with the mental practice method and would be able to continue treatment unassisted.

Even though this case study did not directly address whether mental practice with motor imagery can improve a patient's global level of functioning, the type of movements required by the FST are important for motor skills. It would be interesting to measure in future studies whether improvement on the FST through mental practice maintained over longer training periods generalizes to more ecologically relevant yet sequential tasks such as walking over obstacles. The present findings constitute another step toward the demonstration that this technique could be used as an adjunct to already established rehabilitation methods.

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