ARTICLES

Working Memory and Mental Practice Outcomes After Stroke

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ABSTRACT. Malouin F, Belleville S, Richards CL, Desrosiers J, Doyon J. Working memory and mental practice outcomes after stroke. Arch Phys Med Rehabil 2004;85:177-83.

Objective: To examine the relationship between working memory and motor improvement obtained after a single training session combining mental and physical practice.

Design: Before-after trial.

Setting: Laboratory of a university-affiliated research rehabilitation center.

Participants: A sample of 12 patients with stroke and 14 age- and gender-matched healthy subjects.

Intervention: In a single session, patients were trained with combined mental and physical practice to increase the loading on the affected leg while standing up and sitting down.

Main Outcome Measures: Motor improvement as measured by the percentage change in limb loading on the affected limb after training and 24 hours later (follow-up), and the relationship between working memory and percentage motor improvement.

Results: The loading on the affected leg was improved after training ($P<.01$) and at follow-up ($P<.05$), and working memory scores at follow-up correlated significantly ($P<.004$ to $P<.007$) with the level of improvement. The visuospatial domain yielded the strongest correlation ($r=.83$), followed by the verbal ($r=.62$) and kinesthetic ($r=.59$) domains.

Conclusions: These results suggest that the outcome (improved limb loading) of mental rehearsal with motor imagery depends on the ability to maintain and manipulate information in working memory.

Key Words: Cognition disorders; Memory; Motor skills; Rehabilitation.

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FOR MORE THAN 50 YEARS, mental practice combined with physical practice has been found to promote the learning of motor skills and to maintain the level of performance of athletes when physical practice is not possible.[1-3] Mental practice consists of repeating an imagined movement, through motor imagery, several times with the intention of improving motor performance. Motor imagery, on the other hand, corresponds to a dynamic state during which the representation of a specific action is internally reactivated within working memory without any overt motor output.[4] Two kinds of mental representations of the self in action can be generated; internal or kinesthetic images corresponding to the kinesthetic representation of the action from within (the first-person perspective), and external or visual images involving a visuospatial representation of the action (third-person perspective).[5,6] Mental rehearsal requires that subjects maintain and manipulate visual and kinesthetic information in their working memory. Therefore, an impairment in working memory may hinder the ability to engage successfully in motor imagery, and thus curtail the outcomes of mental practice.

Memory is now considered as relying on the interplay of a number of interacting components. Long-term memory processes are involved in encoding and retrieving information after lengthy delays. Working memory, also labeled short-term memory, is involved in the on-line maintenance and active manipulation of information. Working memory is generally conceived as a multicomponent system, which relies on a complex network of brain areas including temporoparietal areas and frontal areas.[7-9] It is postulated to include an attentional control component, the central executive, as well as stores involved in the short-term maintenance of material of different natures.[10] It is generally agreed that verbal and visual material are maintained in different working memory systems.[11] Verbal information would be retained in a phonological loop with its phono-articulatory properties, whereas a visuospatial scratch-pad would play a role in maintaining spatial information and visual images. A specialized working memory store for kinesthetic material has recently been proposed by Dolman et al.[12] They have hypothesized that 3 domains of working memory—namely, visuospatial, kinesthetic, and verbal—are directly involved in mental imagery and that impairment in working memory should affect mental practice efficacy.

During the last decade, many investigators[13,14] have proposed the use of mental practice in physical rehabilitation as a cost-efficient means of promoting motor recovery after cerebral lesions. To date, mental practice has been used for training the upper extremity after stroke. For example, effects on motor disabilities or impairments have been reported in 2 case studies[15,16] and 1 pilot clinical trial.[17] The assessment of the training effect, however, was made with clinical scales that provided a score of global motor performance rather than a specific measure related to the trained motor skills. Moreover, no study has yet investigated the effect of mental practice on motor skills associated with locomotor function nor examined the impact of cognitive function on mental practice outcomes.

After a stroke, a person's ability to stand from a seated position and to sit down from a standing position is affected. For example, compared with healthy subjects when rising from a chair and sitting down, persons after a stroke take 25% to 61% longer and put much more load on the unaffected leg, thus decreasing the vertical forces on the affected leg by 20% to 25% during the task.[18,19] Given the physically demanding nature of this mobility task (standing up, sitting down), combin-

Table 1: Individual Characteristics and Working Memory Scores of the Subjects With Stroke

Subject	Age (y)	Time Since Onset (y)	Side of Hemispheric Lesion	Working Memory (z scores)		
				Visuospatial	Kinesthetic	Verbal
H1	57	2.10	L	1.57	−0.67	−1.07
H2	57	1.90	R	−0.51	−0.92	−1.19
H3	38	1.85	L	1.42	0.73	0.16
H4	66	0.97	R	−0.19	−0.86	−1.44
H5	73	0.20	R	−1.12	−1.22	−1.07
H6	48	4.50	L	−1.44	−2.24*	−1.61
H7	52	0.33	L	−0.66	0.18	−0.16
H8†	59	2.14	R	−2.78*	−1.98*	−2.30*
H9†	63	0.93	R	−4.90*	−2.24*	−1.25
H10†	54	0.21	L	−2.46*	−2.16*	−2.30*
H11†	43	1.62	R	−3.25*	−2.20*	−1.56
H12†	63	0.76	L	−3.15*	−2.28*	−3.30*
Mean	56.10	1.46	6L/6R	−1.46	−1.32	−1.45
SD	9.89	1.20		1.91	1.03	0.89
Range	43–73	0.21–4.50		1.57 to −4.9	0.73 to −2.3	0.16 to −2.9

Abbreviations: L, left; R, right.
*z scores lower than 1.64 equal to $P<.05$.
†H8 to H12: patients with z scores lower than 1.64 on at least 2 domains of working memory.

ing mental practice with physical practice should provide additional practice with less physical effort to improve the motor performance. Moreover, measuring the changes in the amount of force exerted by the affected leg after training should provide a measure of improvement related to the training of the task.

Thus, the purpose of our study was to examine the relationship between working memory and motor improvement obtained after a single training session combining mental and physical practice. It was hypothesized that gains after training would be greater in patients with better working memory.

METHODS

Participants and Experimental Design

Twelve patients with residual motor impairment on 1 side of the body (hemiparesis), resulting from a first cerebrovascular accident, and 14 age- and gender-matched healthy subjects participated in the study (table 1). To be included, the patients had to be between the ages of 30 and 75 years, have a unilateral locomotor disability consecutive to a stroke, demonstrate motor imagery ability, and be able to stand up and sit down from a chair without using their hands. Patients were excluded if they had a cerebellar or brainstem lesion, receptive aphasia, or moderate to severe body and visuospatial hemineglect or apraxia. The motor performance of the trained task (standing up, sitting down) was assessed before training (baseline), after a single training session (posttest), and 1 day later (follow-up). Subjects in both groups were submitted to similar testing procedures, but the training was conducted only in the group of patients. All subjects gave written informed consent for their participation in the study. The protocol was approved by the Ethics Committee of the Institut de réadaptation en déficience physique de Québec, where the study was conducted.

Assessment Procedures

Motor imagery ability. Motor imagery ability was assessed with a chronometric test and a motor imagery questionnaire: the Kinesthetic and Visual Imagery Questionnaire (KVIQ) is a modified version of the Movement Imagery Questionnaire[20]

(MIQ). It includes a series of 10 gestures scored for visual and kinesthetic components on a 5-point ordinal scale.[21] The gestures comprise movements of the head (flexion-extension), shoulders (elevation), trunk (flexion), upper limbs (shoulder flexion, elbow flexion-extension, finger opposition), and lower limbs (knee extension, hip abduction, hip external rotation, foot tapping). In the KVIQ, participants are required to execute each movement physically and to immediately imagine the same movement as if they were seeing and feeling themselves performing the movements from within. The subjects rate their capacity to elicit mental images of the action on two 5-point scales (1, low imagery; 5, high imagery). One scale rates the clarity of the image (visual score), and the other rates the intensity at which subjects can feel themselves executing the movement (kinesthetic score). The KVIQ has been validated (Cronbach $\alpha=.92$), and its concurrent validity with the MIQ ($r=.61$) has been reported in a group of healthy subjects.[22]

The Motor Imagery Screening Test (MIST) is a chronometric test similar to other existing chronometric tests for walking[23] and foot-tapping[24] tasks, described previously. In this test, subjects were instructed to imagine stepping movements (eg, placing 1 foot forward onto a 3-cm high block and back on the floor) and to verbally signal each time they placed the foot on the step until the evaluator told them to stop. Each trial terminated after varying time periods (25s, 15s, 35s; presented randomly). The test was repeated with subjects executing the stepping movements physically over the same time periods. In addition to the number of stepping movements, the duration of each simulated and physical stepping movement was also recorded with a stopwatch, for further comparison between movement times of simulated and physically executed movements. The test was performed with the unaffected leg, and the mental stepping always preceded the physical stepping.

Working memory. Three domains of working memory were assessed: visuospatial, verbal, and kinesthetic. The procedure involved measuring immediate serial recall (or span measurement) for each type of material. This is a standardized procedure[25] that has been widely used with persons with brain injury.[11] The examiner presents a series of items and asks the subject to reproduce it immediately in the same order. For each

domain, items are taken randomly from a limited pool of items and are presented sequentially. For each type of material, 5 lists of 2 items were first presented. If the subject could reproduce correctly 3 of the 5 lists, the list length was increased by 1 item; otherwise, testing was interrupted. The verbal stimuli were taken from a set of 9 frequent and imaginable monosyllabic words presented in the auditory modality.[26] In the visuospatial condition, the examiner tapped on a series of 9 blocks presented in a random arrangement in front of the subjects. The subject was asked to reproduce the sequence by tapping on the same blocks.[27] In the kinesthetic condition, the same standardized procedure was used as above, but the stimuli were constructed to test working memory for movement. The examiner produced a series of gestures, and the subject was asked to reproduce them. These gestures were taken from a set of 6 predetermined simple movements selected on the basis of their relevance to the training task. The gestures involved unilateral and bilateral lower-limb movements, as well as movements involving the trunk, the intact upper limb, and the affected lower limb (see appendix 1).

Motor performance. The ability to exert vertical force with the affected leg during standing up and sitting down was used to assess the motor performance. Subjects were seated on a chair with the seat height standardized to 100% of the lower-leg length. The chair and each foot were placed on 1 of 3 separate forceplates. The subjects were instructed to look forward and, on hearing an auditory cue (tone), they were requested to stand without using their hands and to sit down on a second auditory cue. Five trials were collected at baseline, immediately after the training session, and 24 hours later. Signals from the forceplates were recorded synchronously at a sampling rate of 1000Hz and stored for further analysis. The net vertical force signal, which corresponds to the vertical force overload (the unaffected minus the affected leg), was also sent to another computer to be displayed on a monitor located in front of the subject during the familiarization period. The outcome measure (dependent variable) was the vertical force overload ($Nm \cdot ms \cdot kg^{-1}$); this value corresponds to the time integral of the net vertical force signals (Nm) calculated for the task duration (ms) and normalized to the subject's mass (kg).

Training procedure. The training session began with a familiarization period during which patients were provided with a visual display of the net vertical force signal, indicating the magnitude and timing of the vertical force overload on either the unaffected or affected leg. They were instructed to modify how they planned and executed the task (motor strategies), to reduce the overloading on the unaffected leg while increasing the loading on the affected leg. They were asked to relate their motor strategy to the outcome viewed on the screen and to remember the feeling and the movement sequences associated with success or error, in order to develop an inner image of their performance. They were also instructed to describe verbally what they did to improve their performance (eg, "shift my body to the right and then move forward and up"), so that they could reactivate these pointers later during mental practice. The visual display was then taken away, and the patients had to rehearse mentally the proper motor strategy. This was followed by training per se, which consisted of a series of blocks, each including 1 physical practice repetition (PP) and 5 mental practice (MP) repetitions (1PP/5MP training ratio). For the physical repetition, patients were instructed to stand up and sit down when they heard the auditory cue, as they had done during the baseline testing. For the mental rehearsal, they were instructed to close their eyes, to imagine they were standing up and sitting down, and to signal verbally the beginning and end of each repetition.
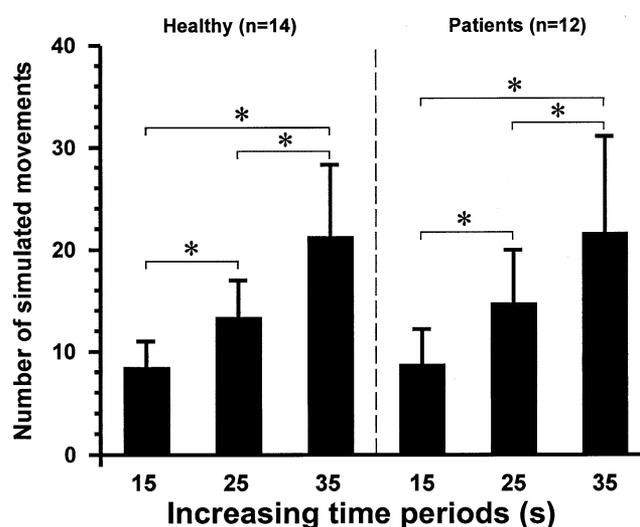

Fig 1. Motor imagery–screening test. The mean ± SD number of simulated movements during the 3 time periods for the healthy subjects and the subjects with stroke. There was a significant increase in the 2 groups with time (ANOVA, $P<.0001$). *$P<.01$ (post hoc procedures).

Data Reduction and Statistical Analyses

The number of simulated stepping movements for each of the 3 randomly presented time periods from the MIST was averaged. In addition, differences in the duration between physical and simulated stepping movements were calculated for each of the 3 time periods and averaged. The total scores from the visual and the kinesthetic scales of the KVIQ were averaged. Three parameters of the working memory were analyzed: the span size, corresponding to the longest sequence, correctly recalled on at least 3 of 5 trials; the number of sequences; and the number of items correctly recalled. These raw scores were then converted to z scores by comparison with corresponding data from the healthy subjects. The combined z scores from the 3 parameters were used to identify patients with working memory impairment. Motor improvement was measured using the percentage changes in the overloading of the unaffected leg ($Nm \cdot ms \cdot kg^{-1}$) posttraining and at follow-up. To measure the level of motor impairment, the overload values were converted to z scores by comparison with corresponding data from the healthy subjects.

The relationship between working memory and motor improvement was studied with the Pearson correlation coefficient. The effects of training were determined by examining the changes in the overloading over time using a 1-way analysis of variance (ANOVA) for repeated measures, followed by the Scheffé post hoc test. The nonparametric Mann-Whitney U test was used for between-subgroup comparisons and the Wilcoxon test for within-group comparisons.

RESULTS

The individual characteristics of the patients (10 men, 2 women) are reported in table 1. The mean age ± standard deviation (SD) (53.7 ± 11.6y) of the healthy subjects (11 men, 3 women) was similar to that of the group of patients ($P>.05$).

Motor Imagery Ability

The bar graphs in figure 1 illustrate the outcomes of the MIST for the 2 groups. In each group, the number of simulated

Table 2: KVIQ Scores

	Visual (max=50)	Kinesthetic (max=50)
Subjects with stroke		
Median	39.5	30
Mean ± SD	38.1±7.8*	30.8±8.9
Range	20–49	17–46
Healthy subjects		
Median	37	35
Mean ± SD	36.9±9.3	35±8.4
Range	17–46	21–49

*Within-group difference $P<.05$ (Wilcoxon test).

movements increased significantly with time ($F_{2.26}$=114.9, $P<.0001$), and the increase was parallel in the 2 groups (no group by time interaction). Post hoc analyses indicated a significant increase in the number of simulated movements ($P<.01$) with increasing time period in the 2 groups. Comparison of the mean KVIQ scores showed that both groups had similar visual and kinesthetic perceptions of their ability to imagine motor actions (table 2). Further analyses, however, demonstrated that the mean visual scores in the patients were higher than their kinesthetic scores. Moreover, there was no relationship between their respective visual and kinesthetic scores ($r=.01$). The latter finding contrasts with the significant correlation ($r=.65$) found between the visual and kinesthetic scores in the healthy subjects and the lack of difference between their visual and kinesthetic scores.

Working Memory and Motor Improvement

The mean span size of each group is illustrated in figure 2A. The patients' span size was smaller on all 3 tasks. The mean z scores calculated for each task (visuospatial, verbal, kinesthetic) in figure 2B indicate that patients showed a comparable level of impairment across tasks. As revealed by the size of the SDs, the level of impairment varied markedly across patients (table 1). Six patients (H1 to H5, H7) showed no deficit in working memory; subject H6 was impaired on the verbal task only. Five others had significantly lower scores on 3 (H8, H10, H12) or 2 (H9, H11) of the tasks, respectively.

Figure 3A illustrates the mean overloading (and SD) on the unaffected leg during the mobility task at the 3 time points. These values decreased significantly ($F_{2.26}$=14.8, $P<.0001$) after training (post hoc procedures, $P<.01$) and at follow-up ($P<.05$), indicating that patients learned to exert greater vertical force with the affected leg. Strong relationships between working memory and motor improvement (fig 3B) were found at follow-up, with the strongest correlation occurring on the visuospatial task ($r=.83$, $P<.007$), followed by the verbal and kinesthetic tasks (table 3). Table 4 shows that scores from the kinesthetic domain were strongly associated with both visuospatial and verbal domains.

Patients were then divided on the basis of their working memory ability, as measured by the z scores. Patients with a z score 2 SD lower than the reference values from the control group (-1.64 and lower) on at least 1 working memory task (subjects H8 to H12, table 1) were included in the impaired working memory subgroup. Patients with z scores within normal values on at least 2 working memory tasks were included in the normal working memory subgroup. Comparison between the subgroups (table 5) revealed that patients in the normal working memory group had larger motor improvement and performed better than patients in the impaired working memory subgroup on the 3 memory tasks. Note also that subjects in

both subgroups had an equivalent motor impairment at baseline and did not differ in age or in time since stroke onset. Finally, the results from the chronometric test (MIST) indicated that the patients in the impaired working memory subgroup overestimated the duration of the mentally simulated stepping.

DISCUSSION

Motor Imagery Ability

The results of the KVIQ showed that both groups had a similar visual and kinesthetic perception of their ability to imagine motor actions. However, patients displayed a mean visual score that was higher than their kinesthetic score, indicating that, contrary to the healthy subjects, it was easier for
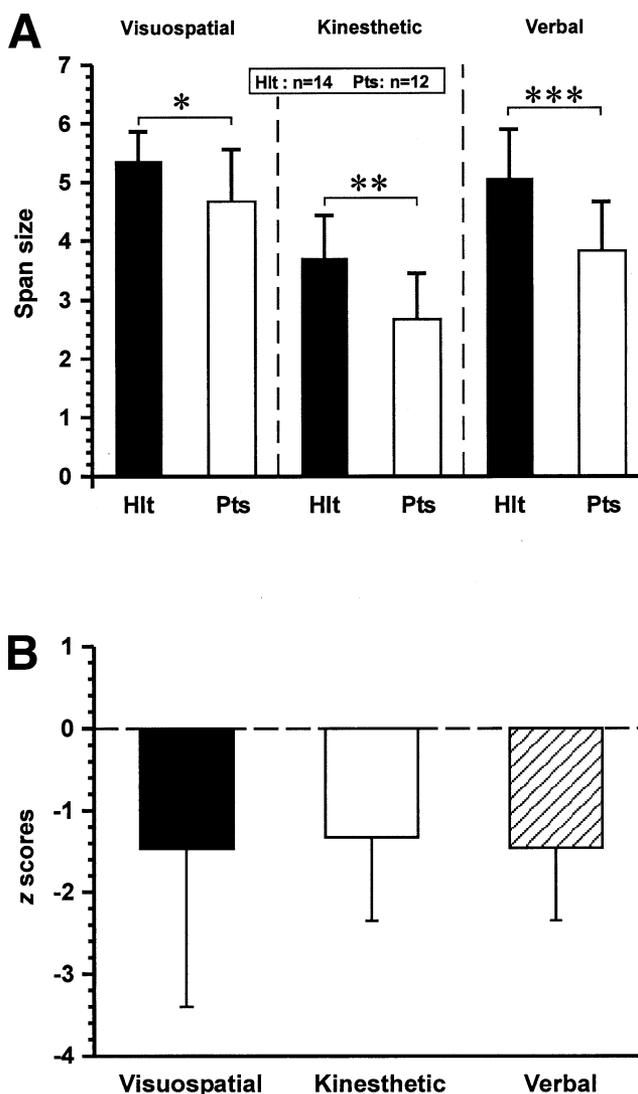

Fig 2. (A) Working memory in healthy subjects and in patients. The mean span sizes ± SD of the 3 working memory domains for the healthy subjects and the subjects with stroke. Significant differences were found between groups for the visuospatial (*$P<.04$), the kinesthetic (**$P<.005$), and the verbal (***$P<.002$) domains (Mann-Whitney U test). Abbreviations: Hlt, healthy subjects; Pts, patients. (B) Impairment of working memory. The mean z scores ± SD for the 3 working memory domains. There were no differences in the level of impairment of the 3 domains of working memory.
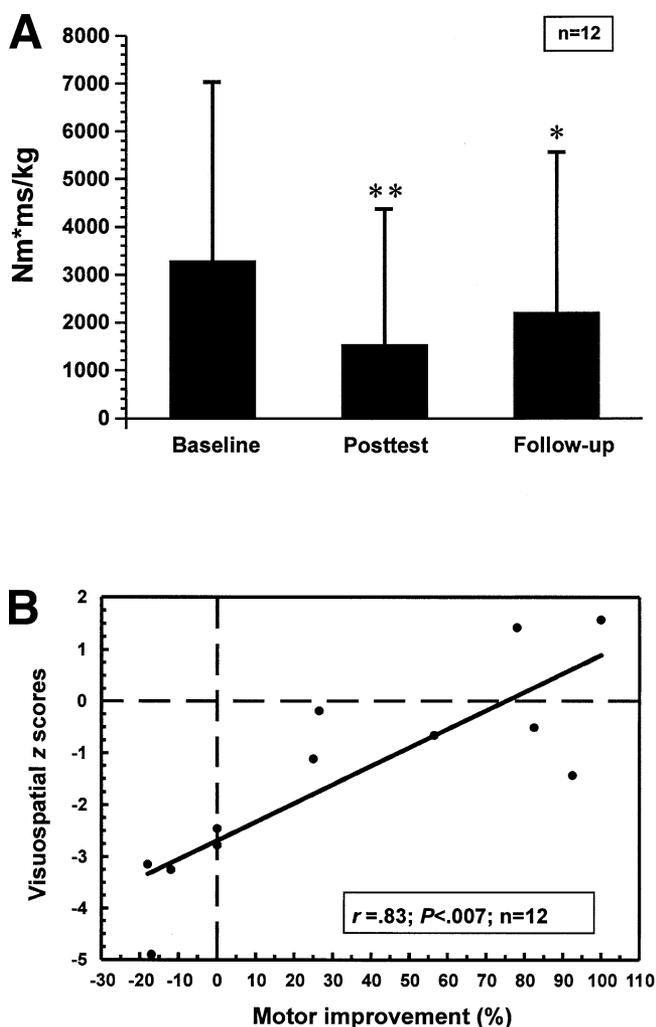
Fig 3. Overloading of the unaffected limb. (A) The mean overloading on the unaffected leg ± SD at baseline, after training (posttest), and 1 day after training (follow-up). The amount of overloading (Nm·ms·kg^{-1}) on the unaffected leg significantly declined after training (*P*<.01 posttest) and 1 day later (*P*<.05 follow-up), which indicates improved limb loading on the affected limb. *P*<.05; **P*<.01. (B) The relationship between visuospatial *z* scores and the percentage of motor improvement at follow-up.

patients to elicit visual images than kinesthetic images. Moreover, in contrast to the healthy group, the visual and kinesthetic scores did not correlate. Such dissociation of visual and kinesthetic imagery is possibly related to the location of the cerebral lesion. Indeed, it has been shown that each type of mental representation of action depends on different brain

Table 3: Pearson Correlation Coefficients Between Working Memory and Percentage Improvement of the Motor Strategy

Working Memory	Motor Improvement (%)	
Domains	Posttest (*r*)	Follow-Up (*r*)
Visuospatial	.33 (NS)	.83 (.007)
Kinesthetic	.26 (NS)	.62 (.03)
Verbal	.45 (NS)	.59 (.04)

Abbreviation: NS, not significant.

Table 4: Relationships Between Working Memory Domains

Working Memory Domains	Pearson Correlation Coefficients (*r*)
Visuospatial and kinesthetic	.82 (*P*<.001)
Kinesthetic and verbal	.80 (*P*<.002)
Visuospatial and verbal	.58 (*P*<.05)

areas.[5,6,28] For instance, prefrontal and right inferoparietal cortex are predominantly activated when subjects imagine someone else[5,6] performing a given action (third-person perspective), whereas kinesthetic imagery (first-person perspective) engages the left inferoparietal cortex[5] as well as other motor-related areas, such as the cerebellum, the supplementary motor area, the dorsal premotor cortex, and the cingulate motor area.[28] Altogether these findings suggest that some patients have more difficulty mentally recalling the kinesthetic sensations related to a motor action than recalling its visual image (third-person perspective) and that, perhaps, the third-person perspective should be used initially for mental practice training.

The results from the MIST provided an objective measure of each subject's ability to engage in motor imagery.[23,24] When asked to simulate stepping movements with their unaffected leg over varying periods of time, patients showed the expected increase with time, which suggests that they were likely mentally rehearsing the stepping movements.

Comparison of movement times between simulated and physical stepping movement from the MIST revealed other interesting new information. Of particular interest is the overestimation of the simulated stepping movements with the unaffected leg seen only in the subgroup of patients with impaired working memory. Based on 2 earlier studies conducted in small groups of patients with cerebral lesions,[29,30] the duration of the simulated and physically executed movements is expected to be similar on both sides, with longer movement times on the affected side. In our study, the duration of simulated stepping on the unaffected side was longer than physical stepping, which resulted in unexpected slowing of the simulated movement on the unaffected side. Such slowing is consistent with findings from a recent study[31] in which bilateral slowing of the mentally simulated movements of the upper and lower limbs was described in a group of 26 persons with stroke. In light of our present results, where the slowing was found only in the subgroup of patients with impaired working memory, the bilateral slowing found in some patients after stroke may reflect a disturbance of the imagery process possibly associated with the cerebral lesions. The possible link between working memory impairment and disturbance in motor imagery process is conjectural at this time, and further investigation in a larger sample of patients with cerebral lesions is needed to examine this relationship specifically.

Impaired Working Memory and Motor Learning

Our results show that all 3 domains of working memory were impaired to a similar degree after stroke but that the level of impairment differed across patients. In addition, the amount of motor improvement at follow-up was strongly associated with the visuospatial working memory domain. The results from the motor imagery questionnaire (KVIQ) may help explain the strong association between the visuospatial domain and motor learning. Given the higher visual scores, it is likely that the patients had a propensity for visual imagery during mental practice, which favors patients with the least impairment in that specific working memory domain. The kinesthetic and verbal working memory domains were also significantly

Table 5: Comparisons of the 2 Subgroups of Patients With Normal Working Memory (n=7) and Impaired Working Memory (n=5)

	Subgroups		Probability*
	Normal Working Memory	Impaired Working Memory	
Motor improvement (%)			
Posttest	72.6±28	27.4±54.1	NS
Follow-up	65.9±30.6	−9.4±8.9	$P<.003$
Total	69.3±24.9	18.4±29.20	$P<.01$
Working memory (z scores)			
Visuospatial	−0.13±1.18	−3.31±0.94	$P<.003$
Kinesthetic	−0.96±0.58	−2.14±0.79	$P<.02$
Verbal	−0.71±0.96	−2.17±0.12	$P<.01$
Motor impairment (z scores at baseline)	−11.4±17.3	−12.5±14.3	NS
Overestimation (s) of simulated stepping	0.01±0.17	0.43±0.28	$P<.007$
Others			
Age (y)	55.9±11.5	56.4±8.4	NS
Stroke onset (mo)	20.3±17.5	13.6±9.1	NS

NOTE. Values are mean ± SD.
*Mann-Whitney U test.

related to mental practice outcomes at follow-up. In fact, during mental training, patients were instructed to recall the kinesthetic sensations and verbal descriptors (words describing specific sequence of movements) associated with the proper motor strategy. Thus, during mental practice, they had to retrieve the kinesthetic sensations as well as verbal information encoded during the familiarization period, and again patients with the higher level of working memory succeeded better.

The finding that the level of working memory was associated with motor improvement at follow-up (24h later), and not at posttest, is consistent with the notion that working memory is involved in learning new motor skills, especially in the initial learning phases.[32] Our findings suggest that an impairment of working memory can also compromise the long-term retention of a skilled behavior with motor imagery, by preventing the establishment of the rich and diversified representation provided by combining verbal, kinesthetic, and visuospatial rehearsal. The involvement of working memory during motor imagery is also consistent with the brain activation patterns observed in several functional imaging studies of motor imagery.[5,6,33]

Many investigators have also documented the existence of cognitive impairments after stroke.[34-38] Although motor deficits have a major impact on functional autonomy, a significant correlation between various components of activities of daily living and 1 or many cognitive components has also been reported.[34-36] For instance, 23% of the variance in performance on a variety of functional outcomes was related to cognitive deficits.[37] Recently, by using a confirmatory factor analysis, the cognitive factor was found to be the third in order of importance, after motor and perceptual factors, in explaining the variance in functional autonomy after stroke.[38] The assessment of cognitive impairments in these studies, however, encompassed multiple cognitive components, which makes the comparison with our results difficult.

To our knowledge, this is the first study that examined the impact of working memory deficits on the learning of locomotor-related skills in persons with stroke. Our results further emphasize the role of cognitive factors on functional outcomes and suggest that cognitive impairments should be taken into account when selecting therapeutic approaches. Given the exploratory nature of this study, other clinical studies are needed to generalize present findings to larger patient populations and

to dissociate gains specific to the addition of mental practice. In future studies, it would be of interest to determine whether the slowing of the imagery process is also observed during the trained task (eg, standing up, sitting down).

CONCLUSIONS

One session of mental practice combined with physical practice resulted in an improvement in the loading of the affected leg during standing up and sitting down. The improvement of the motor skill was maintained 1 day after training, which suggests a learning effect. This learning effect was strongly related to the working memory ability and particularly the visuospatial domain. The subgroup of patients with impairment on at least 2 domains of working memory had a smaller improvement (27% vs 72%) after training and no retention at follow-up. The results from the chronometric test also indicated that patients with impaired working memory displayed a slowing of the mentally simulated stepping movement that may be indicative of a disturbed motor imagery process. Last, present results emphasize the role of cognitive factors on functional outcomes and suggest that cognitive impairments should be taken into account when selecting therapeutic approaches.

APPENDIX 1: KINESTHETIC WORKING MEMORY

Assessment Conditions

The subject is sitting with the feet on the floor and the hands placed on the thighs.

The examiner is sitting beside the subject (on the side of the unaffected limb).

The subject is instructed to observe and to imitate the gestures executed by the examiner; the gestures are not described verbally.

List of Gestures

1 & 2 Are Unilateral (1 lower limb)
1. Lifting the heel of the unaffected limb with toes remaining in contact with the floor.

2. Lifting the unaffected limb (hip and knee remaining flexed 90°) and placing the foot sideways (hip abduction).

3 & 4 Are Bilateral (both lower limbs)

3. Bringing the heel of the affected foot forward (knee extension), and the toes of the unaffected foot backward (knee flexion).

4. Crossing the feet at the ankle under the chair, the unaffected foot moving the affected foot backward.

5 & 6 Are Mixed (trunk, upper, and lower limbs)

5. Flexing the trunk forward to touch the affected ankle with the unaffected hand.

6. Flexing the affected hip (with the knee flexed 90°) and touching the affected knee with the unaffected hand.

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