ORIGINAL ARTICLE

Effects of Motor Imagery on Hand Function During Immobilization After Flexor Tendon Repair

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ABSTRACT. Stenekes MW, Geertzen JH, Nicolai J-P, De Jong BM, Mulder T. Effects of motor imagery on hand function during immobilization after flexor tendon repair. Arch Phys Med Rehabil 2009;90:553-9.

Objective: To determine whether motor imagery during the immobilization period after flexor tendon injury results in a faster recovery of central mechanisms of hand function.

Design: Randomized controlled trial.

Setting: Tertiary referral hospital.

Participants: Patients (N=28) after surgical flexor tendon repair were assigned to either an intervention group or a control group.

Intervention: Kinesthetic motor imagery of finger flexion movements during the postoperative dynamic splinting period.

Main Outcome Measures: The central aspects of hand function were measured with a preparation time test of finger flexion in which subjects pressed buttons as fast as possible following a visual stimulus. Additionally, the following hand function modalities were recorded: Michigan Hand Questionnaire, visual analog scale for hand function, kinematic analysis of drawing, active total motion, and strength.

Results: After the immobilization period, the motor imagery group demonstrated significantly less increase of preparation time than the control group (P=.024). There was no significant influence of motor imagery on the other tested hand function (P>.05). All tests except kinematic analysis (P=.570) showed a significant improvement across time after the splinting period (P≤.001).

Conclusions: Motor imagery significantly improves central aspects of hand function, namely movement preparation time, while other modalities of hand function appear to be unaffected.

Key Words: Hand; Imagination; Rehabilitation; Reaction time; Tendons.

IN OUR EXPERIENCE, a major portion of the patients seen in the emergency department by a hand surgeon have flexor tendon injury of the hand. Flexor tendons enable us to tune finger position so that we can grasp and manipulate objects in our environment. The flexor tendon is surgically repaired by suturing both ends of the severed tendon together. Usually the patient can be discharged within a day. Nevertheless, for the patient, this is only the beginning of a relatively long rehabilitation period that, in our hospital, usually lasts more than 12 weeks.

During the regeneration of the tendon at the repair site, the tendon strength decreases, with a maximum weakness after 2 weeks.[1] Therefore, early active use of a repaired tendon has a risk of tendon rupture. Prolonged static splinting of a hand after tendon repair will result in adhesions leading to permanent disability.[2] The treatment therefore is one that diminishes the risk of both ruptures and adhesions. Currently, most postoperative protocols consist of several weeks of relative immobilization. Passive motion enables sliding of tendons and joints; this prevents adhesions. At the same time strong forces are avoided; this prevents tendon rupture. This is followed by gradually increasing the load on the flexor tendons. Although patients are treated intensively by a team consisting of occupational therapists, physiotherapists, rehabilitation specialists, and plastic surgeons, the final hand function is often suboptimal.[3]

Improvement of the functional outcome after flexor tendon injury can probably not be found in changing the operative technique. Hence, for improvement of functional outcome, we have to focus on the postoperative rehabilitation period. Would it be possible to implement a treatment procedure that is more active without actually stressing the tendons and that may prevent not only the aforementioned negative side effects but also the central reorganization that takes place as a result of relative immobilization? Indeed, it has been shown that (relative) immobilization of a limb results in central reorganization. This leads to temporary forgetting of the function of the affected limb,[4] so that initially after the immobilization period, the central control of movements is inefficient. This means that efficient movements will have to be relearned.

Immobility or injury have shown to result rather rapidly in changes of motor (and sensory) representations in the brain of peripheral organs such as a finger, arm, or leg.[5-8] In general, the representation on the cerebral cortex shrinks as a result from the decreased input,[9-11] whereas stimulation (increased input) leads to enlargement of the representation.[12] Hence, continuous input from a limb appears to be a prerequisite for preservation of the cortical representation of that limb.[13]

In the past, it has been shown that sensory input not exclusively results from actually performed movements. Imagined movements without actually moving the limbs (motor imagery) also generate sensory input.[14,15] Motor imagery and actual practice involve overlapping neural networks.[16-18] Remarkably, movements can be learned and performance improved by motor imagery.[19-21]

List of Abbreviations

MHQ	Michigan Hand Outcome Questionnaire
VAS	visual analog scale

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To our knowledge, the use of motor imagery to improve functional outcome after peripheral injury (and repair) has not been described in literature until now. The objective of this randomized prospective study is to determine whether motor imagery during the immobilization period after flexor tendon injury results in a greater recovery of central aspects of hand function.

METHODS

Subjects

From August 1, 2003, until December 31, 2005, all patients with flexor tendon injury referred to our clinic were screened. Complete sharp transsection of at least a flexor digitorum superficialis or flexor digitorum profundus tendon was an inclusion criterion. Patients were eligible for inclusion if they were between 18 and 65 years of age and suitable for tenorraphy and postoperative dynamic splint therapy. Subjects with fractures, tendon ruptures, and impaired motor function because of a nerve lesion or pre-existent upper-extremity disorders were excluded from participation. Subjects who fulfilled the criteria were asked to fill out a Vividness of Movement Imagination Questionnaire.[22] The Vividness of Movement Imagination Questionnaire consists of an internal and external section. The internal section asks subjects to rate their ability to imagine activities as performed by themselves; the external section asks subjects to rate their ability to imagine activities as performed by others. A high score on the Vividness of Movement Imagination Questionnaire indicates low imaginative powers. Because of the nature of our intervention (imagination), subjects with low imaginative powers (defined as Vividness of Movement Imagination Questionnaire scores >72) were not admitted to the motor imagery group. However, this was the case in only 1 subject, who was assigned to the control group consequently.

The present study was approved by the local medical ethics committee, and 28 included patients gave their written informed consent. The following independent variables were recorded: age, sex, hand dominance, highest level of education, Vividness of Movement Imagination Questionnaire, injury type and side, and anesthesia type.

Intervention

After inclusion, subjects were admitted at random to either the control group or the motor imagery group (with the exception of the single person mentioned) (fig 1). Subjects in both groups underwent the regular treatment: surgical tendon repair. Postoperative treatment consisted of 6 weeks of relative immobilization (Kleinert splint). During the first 4 weeks postoperatively, only passive flexion of the finger joints was allowed, while in the following 2 weeks, place-hold exercises were also practiced: exercises in which a subject flexes the fingers passively with the help of the other hand. The fingers are released, and the patient is supposed to hold the fingers in the flexed position. At night, a wrist band was worn so that the fingers were kept in a flexed position. After this period, active finger flexion was started and gradually expanded.

Subjects in the motor imagery group were instructed to perform active flexion and extension movements mentally during the immobilization period. Subjects were instructed to perform 8 motor imagery sessions a day and enter the actual number of sessions they performed on a form at the end of each day. This movement had to be mentally exercised repeatedly, which means that the subjects imagined the performance of the movement without actually moving the fingers. The instructions were as follows: try to imagine as vividly as possible that you slowly clench your fingers and bend the wrist of your splinted hand. Hold this image for 3 seconds. Next, imagine that you straighten your wrist and stretch your fingers. Repeat these imaginary movements 10 times (1 session).

Assessment of Hand Function

Hand function was assessed at different moments by a number of assessment tools. The main outcome measure was preparation time of finger flexion.[23] Preoperatively, a preparation time test was performed with the uninjured hand (reflecting the preinjury state of the injured hand). This test consisted of a series of visual stimuli that were presented on a computer screen (the picture of a hand with 1 of the fingernails lighting up on the screen). The subject was instructed to press a button (finger flexion) as fast as possible after presentation of the fingernail with the finger that corresponded with the lighted fingernail. Each finger was tested 10 times. This resulted in an average preparation time per hand. Because no difference exists between the left and right hands in healthy subjects, a good estimate of the performance of the injured hand before injury could be obtained by measuring the uninjured hand so that improvement across time could be calculated.[23,24] Preparation time is seen as an indicator of central control processes. It is known that these processes are impaired as a result of the disordered input from the periphery. An increase in preparation time, therefore, indicates a decreased speed of information processing in the brain and less efficient control of hand movements. The recorded preparation times of the injured hand were compared with the preparation times of the uninjured hand, which reflected the preinjury state of the injured hand.

Also preoperatively, an MHQ and a VAS were recorded asking subjects to rate their preinjury status. The MHQ[25] results in a score on the domains of overall hand function, activities of daily living, pain, work performance, aesthetics, and patient satisfaction between 0 and 100 for each hand individually. A high score indicates a good hand function. Improvement on the MHQ compared with preinjury measurement was calculated. Subjects were asked to judge their hand skills on a VAS for each hand individually. This resulted in a score between 0 and 100 for each hand individually. A high score indicates a good hand function. Improvement on the VAS compared with preinjury measurements was calculated.

Kinematic analysis of hand movements during drawing movements was performed for each hand. Kinematic parameters of movements were recorded (drawing accuracy and speed) while subjects drew triangles as accurately and fast as possible on a graphics tablet.[a] Deviation (inaccuracy) standardized for drawing speed was calculated so that measurements could be analyzed and compared easily.[26]

Active total motion[27] was assessed using a digital goniometer (R500 Range of Motion Kit).[b] Total motion per finger was calculated by adding up the active range of motions of all joints of 1 finger. On basis of all measurements of the index, middle, ring, and little fingers of 1 hand, the average total motion per hand was calculated. A high active total motion score represents a good active flexion ability. A ratio with the healthy hand was calculated.

Grip strength and pinch strength[28] were recorded using a digital dynamometer[b] and pinchmeter (H500 Hand Kit).[b] For both hands, the average of 3 grip strength measurements was recorded; also, the average of pinch strength between the thumb and each finger was recorded for both hands.

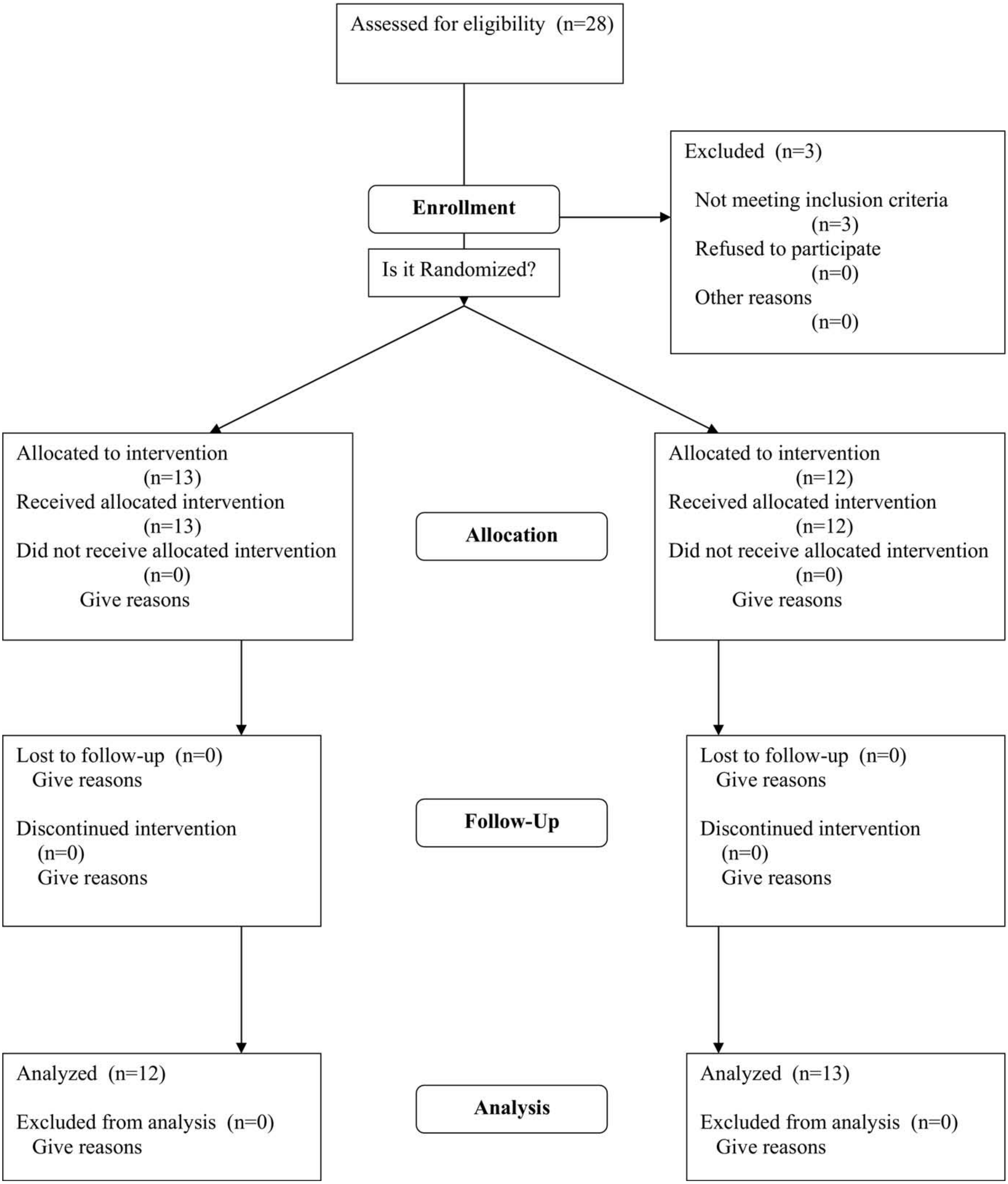

Fig 1. Flowchart of participants through the study.

Table 1: Timing of Recordings

	Preinjury	6wk Postop	7wk Postop	8wk Postop	10wk Postop	12wk Postop
Preparation time	X	X	X	X	X	X
Kinematic analysis		X	X	X	X	X
MHQ	X	X	X	X	X	X
VAS	X	X	X	X	X	X
Active total motion		X	X	X	X	X
Strength						X

NOTE. MHQ and VAS were done preinjury. Preinjury signifies an estimate of the value before the injury took place as explained in Methods. Preparation time values were for the contralateral hand.
Abbreviation: Postop, postoperatively.

For both hands, the preparation time, VAS, MHQ, active total motion, and kinematics were recorded 6, 7, 8, 10, and 12 weeks postoperatively. Strength measurements were recorded only during the last measurement (12 weeks postoperatively). It was not measured earlier because of the increased risk of tendon rupture (table 1). Also, the number of outpatient contacts within 12 weeks after surgery was recorded.

Analyses

Comparison of demographic data of both groups was performed using the Mann-Whitney *U* and Pearson chi-square test. Results of the preparation time test, kinematic analysis, MHQ, VAS, and active total motion were entered in a mixed model with compound symmetry as repeated covariance type and therapy (control vs motor imagery) and the moment the test was taken as factors. Results on the strength measurements were analyzed using the Mann-Whitney *U* test. Statistical tests were performed with statistical software SPSS 14.[c]

RESULTS

In 2 subjects, a fracture (which was not observed on the preoperative radiograph) was found intraoperatively. Another subject was found to have intact tendons intraoperatively. These subjects were excluded so that in total, 25 subjects participated in the study. Table 2 shows the demographics of these subjects subdivided per intervention group (motor imagery/control group). The only independent variable in which the 2 groups differed significantly was the number of tendons injured. Subjects in the motor imagery group had on average 2.3 tendons injured a subject; in the control group this was 1.5 tendons. The average number of recorded motor imagery sessions was 100 (range, 2–294) in the motor imagery group.

The motor imagery group demonstrated significantly less increase of preparation time than the control group ($P=.024$, $F=5.901$). Compared with the initial response time of the uninjured hand, their responses did not slow down as much as in the control group (fig 2).

There was no significant difference between the motor imagery group and the control group in the improvement on MHQ score ($P=.398$, $F=0.723$). Similarly, there was no significant difference between the groups in the improvement on VAS ($P=0.451$, $F=0.597$). The kinematic analysis of drawing also showed no significant differences between the groups ($P=0.165$, $F=2.001$). There was no significant difference between the motor imagery group and the control group in active total motion ($P=0.869$, $F=0.028$).

The average grip strength of the injured hand in the motor imagery group was 28.4±14.9 kg. In the control group, this was 30.6±13.0 kg. The average pinch strength of the injured hand in the motor imagery group was 3.9±1.4 kg. In the control group, this was 3.4±1.6 kg. However, these differences on grip strength and pinch strength were not significant ($P=0.790$, $z=-0.266$; $P=0.457$, $z=-0.744$, respectively).

With the exception of kinematic analysis of drawing ($P=.570$), all variables that were tested more than once demonstrated a significant effect of the moment the test was taken ($P<.001$). This means that subjects improved over time.

Finally, the number of outpatient contacts did not differ significantly between the motor imagery group (average, 20.5 times) and control group (average, 20.6 times; $P=.548$, $z=-0.600$).

DISCUSSION

Because motor imagery simulates movement, it is not surprising that the motor cortex and other motor areas in the brain

Table 2: Demographics of All Subjects, Subdivided per Intervention Group

	Motor Imagery Group	Control Group	Test Statistics *P*
Subjects (n)	12	13	
Age (y)	36.1±11.3	31.1±10.0	.301*
Sex (% male)	75	69	.748†
Dominance (% right-handed)	82	85	.531†
Injury side (% dominant hand)	58	69	.571†
Highest level of education (% finished higher education)	58	54	.291†
VMIQ internal	45.4±16.3	53.9±16.7	.242*
VMIQ external	44.7±13.2	51.8±17.8	.320*
Number of tendons injured	2.3±0.5	1.5±1.0	.019*

NOTE. Values are mean ± SD unless otherwise indicated. The right column shows the statistics of tests of difference between the 2 groups.
Abbreviation: VMIQ, Vividness of Movement Imagination Questionnaire.
*Mann-Whitney *U* test.
†Pearson chi-square test.

are involved in motor imagery.[29-31] In a functional magnetic resonance imaging study with healthy subjects, both a motor imagery group and physical practice group improved on a button pressing task compared with a no practice group. In both cases, this improvement was accompanied by increased activity in the basal ganglia (striatum).[32] The prefrontal cortex and its connection to the basal ganglia are also important in motor imagery by maintaining dynamic motor representations in working memory.[15,33] An earlier positron emission tomography study by our group showed activity in the basal ganglia during finger flexion movements in subjects after flexor tendon injury had been treated and function recovered. However, immediately after the splinting period, this activity in the basal ganglia was absent.[4] Continuing activity in the basal ganglia by motor imagery may prevent the central decay that occurs during immobilization.

The purpose of this randomized prospective study was to determine whether motor imagery training could play a role in the prevention of central decay resulting from immobilization. The results indicate that subjects in the motor imagery group had a significantly lower increase in preparation time after the splinting period than the control group, indicating indirect evidence for a central effect of motor imagery. This is not at all trivial, because it means that the repeated mental performance of movements may prevent the impairment of central control, at least in terms of the speed of information processing.

Although this has not been shown before in an applied rehabilitation study after peripheral injury, short-term effects of motor imagery on preparation time have been shown before in a study with healthy subjects.[34]

We did not find any effects of motor imagery on muscle strength. This corresponds to work by others.[35-37] In literature, however, this is controversial. Some studies with healthy subjects did report an increase of muscle force compared with a control group.[20,38]

We found no influence of motor imagery in subjective measures such as the MHQ or VAS. Also, hand function that appeared to relate more to the physical state of the periphery (total motion, deviation during drawing triangles and strength) was not influenced by motor imagery. Dependent variables that were measured more than once showed a significant improvement across time after the splinting period. The only exception was the result on the kinematic analysis of drawing: although the figure showed a decrease of deviation in time, this was not significant.

We found an effect of motor imagery on central mechanisms of hand function, but not on other aspects of hand function. The number of outpatient contacts was not influenced by motor imagery. Retrospectively this was no surprise because currently patients follow a protocol in which they visit the outpatient clinic at set moments rather than depending on their hand function. Probably the occurrence of complications rather than hand skills dictates the number of outpatient contacts.

It was difficult to control the patients' compliance in the imagery condition. We tried to overcome this problem by asking subjects to record the number of imagery sessions they performed each day. These records showed that the subjects were not all equally compliant. This may have led to an underestimation of the effects of motor imagery.

Furthermore, the optimal dosage of motor imagery training is unknown in rehabilitation after peripheral injury. Studies on the effects of motor imagery in the central nervous system after injury describe several 1-hour periods consisting of several imagery sessions.[39-41] However, it does not seem feasible that subjects with flexor tendon injury will invest several hours a day in motor imagery training because they usually have a more modest potential profit from motor imagery.

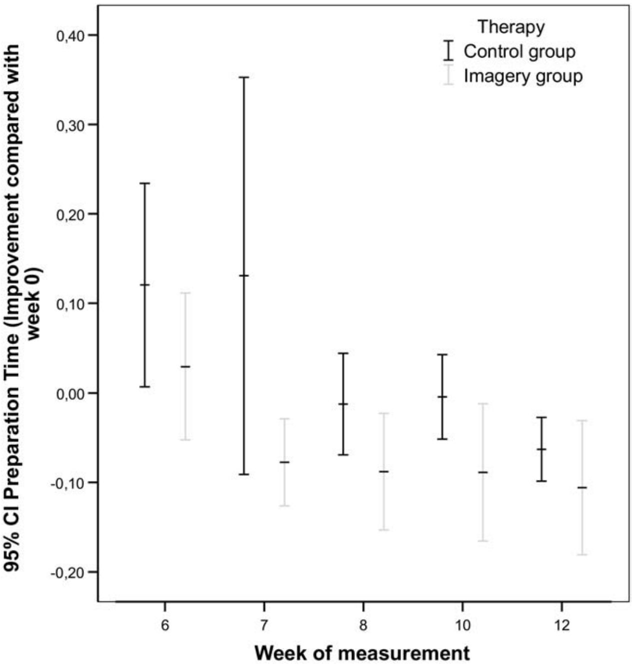

Fig 2. Average extension on preparation time and 95% confidence interval. Abbreviation: CI, confidence interval.

The term *motor imagery* refers to several methods of mental rehearsal of movements such as visual imagery (eg, mirror therapy, watching an affected hand move by mirroring the healthy moving hand or watching a video of a movement) or kinetic imagery (supposedly associated with kinesthetic feeling, without visual input). Although there are relevant areas for both types of imagery and actual execution of movements, they are not identical.[42] Recent studies demonstrated that kinesthetic rather than visual motor imagery modulates corticomotor excitability and motor imagery–based learning.[43,44] Therefore we chose kinesthetic motor imagery in our study.

Subjects in the motor imagery group had more severe injury than subjects in the control group. This may have led to an underestimation of the effects of motor imagery. A larger study or case-control study may eliminate this factor and provide more power.

Currently, numerous studies have been published regarding the usefulness of motor imagery in rehabilitation after central nervous system disorders.[39,40,45,46] It has also been shown that motor imagery has a beneficial effect on motor sequence learning.[47,48] Another field in which the positive effects of motor imagery have been described is sports performance.[49-51] Rosen and Lundborg[52] described a pilot study using a mirror for rehabilitation after hand surgery. To our knowledge, the present study is the first attempt to evaluate the effects of motor imagery on rehabilitation after peripheral injury.

CONCLUSIONS

Motor imagery positively influences central aspects of hand function (ie, preparation time) during the rehabilitation after flexor tendon repair, while other hand function modalities appear to be unaffected. In our study, subjects were followed for 12 weeks. Whether motor imagery will have clinical significance and influence long-term recovery after flexor tendon injury and diminish the disability-to-work period is a relevant question. This aspect should be studied in the future. Future work should also focus on optimizing motor imagery training protocols, patient satisfaction, and disability-to-work. Larger (injury severity–matched) patient groups should be studied so that stronger conclusions can be drawn regarding central and peripheral measures.

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