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Motor Imagery Ability in Patients with Traumatic Brain Injury

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ABSTRACT Motor imagery ability in patients with traumatic brain injury

Objective: To assess motor imagery (MI) ability in patients with a moderate to severe traumatic brain injury (TBI).

Design: Prospective, behavioral study with matched control subjects

Setting: Rehabilitation unit in a university hospital

Participants: Patients with a TBI (mean coma duration 18 days) receiving rehabilitation (n=20) and healthy control subjects (n=17) matched for age and level of education

Interventions: not applicable

Main Outcome Measures: The vividness of MI using a revised version of the Movement Imagery Questionnaire (MIQ-RS), temporal features of MI using the Time Dependent Motor Imagery test (TDMI), the temporal congruence test, and a walking trajectory imagery test. A mental rotation test was used to measure MI accuracy.

Results: The results of the MIQ-RS revealed a decrease of MI vividness in the TBI group. For the TDMI test, an increasing number of stepping movements was observed with increasing time periods in both groups. The TBI group performed a significantly smaller number of imagined movements in the same movement time. The temporal congruence test showed a significant correlation between imagined and actual stepping time in both groups. The walking trajectory test disclosed an increase of the imagined and actual walking time with increasing path length in both groups. The results of the hand mental rotation test indicated a significant effect of rotation angles on imagery movement times in both groups, but rotation time was significantly slower in the TBI group.

Conclusions: Patients with a TBI demonstrated a preserved MI ability, although the results of the extensive clinical test battery indicated a significant decrease of MI vividness, temporal coupling and accuracy.

Key words : Traumatic brain injury; Motor imagery; Rehabilitation

List of abbreviations :

MIQ Movement Imagery Questionnaire

MIQ-R Movement Imagery Questionnaire- revised

MIQ-RS Revised version of the MIQ-R

TDMI Time Dependent Motor Imagery

TBI Traumatic Brain Injury

CTL Control

Motor imagery is the imagining of an action without its actual execution. It is a process during which the representation of an action is internally reproduced within the working memory without any overt output[1]. Mental practice can be described as a cognitive process in which movements are repeatedly mentally simulated without any overt body movement[2]. There is evidence that mental practice as an additional therapy has effects on motor recovery after damage to the central nervous system. Since mental practice based on motor imagery is not dependent on residual motor function, it can be used in neurological rehabilitation to train the more cognitive aspects of motor tasks and thus improve physical recovery[2-8]. However, before starting mental practice, it is imperative to assess whether the patient is still able to engage in motor imagery[9]. Unrelated to cerebral damage, there are individual differences in motor imagery ability. Hall et al[10] classified subjects as high or low imagers based on their Movement Imagery Questionnaire (MIQ) scores. They demonstrated that individual differences in motor imagery ability can influence motor task performance, with high imagers reproducing movements more accurately than low imagers[11]. Moreover, since motor imagery and motor execution are believed to share a similar underlying neural network, any structural damage to the brain could affect both motor performance and motor imagery[9]. Therefore, patients with impaired motor imagery ability should be identified before starting any imagery therapy. Motor imagery ability has already been assessed in several clinical populations. Individuals with motor impairments due to brain lesions caused by stroke, cerebral palsy or Parkinson's disease, seem to show only partially preserved motor imagery capacities[12-17]. We will assess motor imagery ability in patients with a moderate to severe head injury using MIQs, a mental chronometry paradigm and mental rotation tasks[18]. MIQs measure the vividness of motor imagery[19]. Subjects are asked to indicate the ease with which they are able to imagine a certain movement. Several studies indicate that ratings from imagery questionnaires provide a good indication of the ability to generate vivid images of movements[10,19-22]. The MIQ-revised (MIQ-R) is a self-report questionnaire, developed by Hall et al, to assess visual and kinesthetic modalities of movement imagery[10]. A revised version, the MIQ-RS, was developed by Gregg et al[20] to measure the visual and kinesthetic components of motor imagery ability in patients with motor impairments. The MIQ-RS is composed of 2 subscales of 7 relatively simple movements, for use in people with limited mobility, e.g. bending forward or pulling a door handle.

Mental chronometry paradigms measure the temporal coupling between actual and imagined movements. Several investigators have demonstrated that it takes a similar amount of time to imagine and execute an action[23-25]. The match between imagined and actual movement times indicates a reliable use of motor imagery. Malouin et al confirmed the reproducibility of the temporal congruence test and the Time Dependent Motor Imagery (TDMI) screening test for measuring the temporal behavior of motor imagery in healthy subjects and persons poststroke[25]. We also introduced a walking trajectory test to quantify imagery of gait. This test, which was developed by Bakker et al., demonstrated a high temporal congruence between actual and imagined walking in a healthy population[23].

Finally, mental rotation tasks, which measure implicit motor imagery ability and accuracy, are based on the fact that the mental rotation time of a picture depends on the angular rotation of that picture[26]. Moreover, using bodily stimuli, the mental rotation time follows the biomechanical constraints, in that biomechanically more difficult orientations result in slower reaction times[22]. In our study, we used a hand mental rotation test that was a two-dimensional variant of Parsons's hand laterality test, with imagined movement times measured without subjects making a left-right judgment[27].

To our knowledge, motor imagery ability in persons with a moderate to severe traumatic brain injury (TBI) has not been investigated. The present study was primarily designed to examine motor imagery ability in patients with a moderate to severe TBI, using an MIQ, mental chronometry paradigms and a mental rotation task. If motor imagery ability is at least partially preserved in these patients, then this cohort could potentially benefit from motor imagery training in the future.

Methods

Study Design and Participants

Twenty patients receiving rehabilitation after a moderate to severe TBI (TBI group) and 17 healthy control subjects (CTL group) of comparable ages and level of education volunteered and were recruited to take part in this study. All subjects gave informed consent and the protocol was approved by the ethics committee of the university hospital where the study took place.

Table 1 summarizes the participants' characteristics, and Table 2 describes the main cerebral lesions of the trauma patients.

Measures

The Movement Imagery Questionnaire. In order to complete the MIQ-RS, 4 steps were required. First, the starting position of the movement was described by the examiner and then the subject was asked to assume it. Second, the movement was described and then the subject was asked to perform it. Third, the subject was asked to reassume the starting position and then imagine producing the movement (no actual movement was made). Finally, the subject was instructed to rate the ease/difficulty with which he/she imagined the movement on a 7-point scale, where 1 = very difficult and 7 = very easy to picture/feel.

Time Dependent Motor Imagery screening test. For the TDMI test, the subjects were seated on a chair and were instructed to imagine stepping movements over varying time periods. The stepping movement consisted of placing one foot forward on a board and then placing it back on the floor. First, the examiner demonstrated the movement and then the subjects were instructed to actually perform the movement physically twice. During the imagery task, the subjects were asked to close their eyes and to count each time they imagined touching the board. Each subject completed 3 trials. Each trial terminated after a varying time period of 15, 25 and 45 seconds. The examiner recorded the number of imagined movements in these 3 time periods.

Temporal congruence stepping test. For this test, the subjects were seated in a chair and were instructed to first imagine and then to physically perform 5 stepping movements, placing the foot on the board in front of them. During the imagery task, the subjects had their eyes closed. The examiner recorded the duration of the 2 stepping series.

Walking trajectory test. For this test, the subjects were seated in a chair in front of a computer screen that displayed photographs of 3 walking trajectories (Figure 1). The walking trajectories had a varying length of 2, 5, and 10 m. The beginning of the walking trajectory was marked with a blue line, the end with a cone. There were 2 practice sessions, an imagery session and an actual walking session. Each imagery session started with the presentation of a photograph of a walking trajectory. The subjects were then asked to close their eyes and to imagine walking along the path. The examiner recorded the duration of each trial. Subsequently, the subjects performed the actual walking trial. The actual walking session was always performed after the imagery session to minimize the amount of tacit knowledge about the time it actually takes to walk along the trajectory.

Hand mental rotation test. The subjects were seated on a chair, facing a computer screen that displayed photographs of left and right hands. The hands were presented in varying two-dimensional orientations of 30°, 60°, 90° and 120°. Stimuli were presented in a random order. The subjects were instructed to imagine moving their hands from the upright position, palm down, to the position of the stimulus hand and to press the enter button as they completed their imagined action.

Statistical Analysis

Statistical analyses were performed with SPSS Statistics 17.0 software. Data are expressed as mean ± SD. Independent samples *t*-tests were used to investigate between-group differences after confirming homogeneity of variances (Levene's test). For nominal scale data, Pearson's Chi-square tests were used. Repeated measures analyses of variance were used for the data analysis of the TDMI, the walking trajectory test, and the hand mental rotation test with Group (TBI, CTL) as between-subjects variables. Pearson correlations were calculated to evaluate the strength of the association between variables of at least interval scale. In all cases, differences were considered significant if the obtained *p*-value was smaller than 0.05.

Results

We report the results from 20 TBI subjects and 17 healthy volunteers. We found no significant differences in age, level of education, or male/female ratio between the two groups.

The total MIQ-RS score and its kinesthetic and visual subscores were significantly higher (always $P<.05$) in the CTL group than in the TBI group, with a mean total score of 83 (SD 11) and 72 (SD 13), respectively. Further analysis showed significantly higher scores for

MIQ-RS visual (T=-2.92, P<.01) and MIQ-RS total (T=-2.48, P=.024) in patients with frontal brain damage (n=11) compared to patients with extra-frontal damage (n=8). The MIQ-RS total score was not significantly correlated with the results of the mental chronometry tests (temporal congruence test: r=0.06, P=0.73; walking trajectory test: r=0.06, P=.72).

A repeated measures analysis of variance of the TDMI data with time period (15s, 25s, and 45s) as within-subject factor and group (TBI, CTL) as between-subject factor disclosed a significant main effect of time period with increasing imagined steps over longer time periods ($F_{2,34}$ = 153.5, P<.001). A significant main effect of group revealed less imagined stepping in the TBI group ($F_{1,35}$ = 15.5, P<.001), and a significant period by group interaction effect showed that this difference increased with longer time periods ($F_{2,34}$ = 10.6, P<.001). This interaction effect is depicted in Figure 2.

The temporal congruence stepping test scores revealed a statistically significant correlation between imagined stepping time and actual stepping time in both groups (TBI group, r=0.82, P< .001 and CTL group, r=0.80, P<.001). We found no statistical differences in the actual stepping/imagined stepping ratio between the two groups.

A repeated analysis of variance was performed to analyse the walking trajectory test with condition (executed, imagined) and distance (2m, 5m, 10m) as within-subject factors and group (TBI, CTL) as between-subject factors. A significant main effect of condition showed longer durations for the imagery conditions ($F_{1,35}$ = 17.4, P<.001), and a significant main effect of distance revealed longer distances leading to longer performance times ($F_{2,34}$ = 81.8, P<.001). A significant main effect of group showed consistently longer response times for the TBI group ($F_{1,35}$ = 9.9, P = .003). Significant condition by group, and distance by group interaction effects showed that the TBI patients took relatively longer over the imagery conditions and over longer trajectories than the CTL group, $F_{1,35}$ = 8.9, P = .005 and $F_{2,34}$ = 6.8, P = .003, respectively. A strong relationship between imagined and actual walking times was found in both groups (TBI: 10m, r = .65, P = .004; CTL: 10m, r = .61, P = .005), but the actual walking time/ imagined walking time ratio was significantly increased in the TBI group (T_{35}= -2.26, P=.03). Further analysis revealed a significantly higher ratio (worse performance) in patients with frontal brain damage compared to patients with other lesion localizations (T= 2.19, P=.04) and a significantly higher ratio (better performance) in patients with diffuse axonal injury (n = 10) compared to those with predominantly cortical damage (n = 9, T = -2.8, P = .01).

The results of the hand mental rotation test indicated a statistically significant main effect of rotation angle on imagined movement times with increasing angles resulting in increasing movement times ($F_{3,33}$.= 17.0, P<.001). A main effect of group was also obtained showing a significantly slower execution of the imagined hand rotations in the TBI group ($F_{1,35}$ = 5.8 , P=.02). We found no group by angle interaction effect. These effects are illustrated in Figure 3.

Discussion

The present study was designed to assess motor imagery ability in patients with a moderate to severe TBI. Before starting mental practice in neurological rehabilitation, it is necessary to establish whether patients are still able to imagine movements and thus benefit from motor imagery training. We used questionnaires, mental chronometry and mental rotation tasks to study motor imagery abilities in adults with TBI. The results achieved in our study cohort provide evidence that the ability to internally represent movements is preserved after TBI but motor imagery is less vivid and less accurate, with imagined movements performed more slowly than actual movements. To our knowledge, this study is the first to assess the vividness of motor imagery in TBI patients. The visual and kinesthetic scores of the MIQ-RS were lower in the patient group compared to the healthy control subjects. These results appear to conflict with those of studies investigating motor imagery ability after stroke. Malouin et al found the vividness of mental images after stroke to be similar to that in age-matched control subjects. However, motor imagery ability was not symmetrical, with an overestimation when imagining limb movements of the unaffected side[16]. Relying on the subjects' self report , Kimberly et al found no difference in motor imagery ability between subjects with stroke and healthy control subjects[29]. The dominance of visual motor imagery, usually observed in healthy adults, was not confirmed in the present study. Possibly, the use of an adapted scale with relatively simple motor tasks influenced the ease with which the kinesthetic component of the imagery task was performed.

The TDMI, the temporal congruence test and the walking trajectory test have been standardized and their test-retest reliability has been confirmed[25]. The results of the present study support the relevance of these mental chronometry tests for use in a population requiring neurological rehabilitation. Imagined/actual movement time ratios offer a means to quantify the changes in the temporal characteristics of motor imagery. In all mental chronometry tasks, a significant correlation was found between executed and imagined movement times in both the TBI and the CTL group. In all tasks, however, the imagined/actual movement time ratios were significantly increased in the TBI group, indicating a temporal uncoupling between actual and imagined movements. These results are consistent with the findings of other studies. Malouin et al reported increased imagined/executed movement time ratios in patients with stroke[25] and Caeyenberghs et al, who investigated motor imagery ability in children with brain injury, found an inferior ability to imagine the time needed to complete goal-directed movements[30].

Johnson et al found no evidence that chronic limb immobility after stroke compromised the ability to internally plan movements of the paretic arm. In their study, both groups performed at a comparable high level of accuracy on a mental rotation task[31].

We also investigated the relationship between the different motor imagery measures and found no correlation between the results of the imagery questionnaires and those of the mental chronometry tasks in either group. Possibly, anosognosia, a disturbance of self-awareness, limits the usefulness of these self-report questionnaires in a brain-injured patient group since many patients underestimate the severity of their cognitive functioning deficits[32,33]. Moreover, as shown in Table 2, many patients had frontal lobe damage, which is known to be involved in anosognosia pathogenesis[33]. The present study showed that patients with frontal lobe damage had difficulties in assessing their motor imagery ability with overrated scores of the MIQ-RS, compared to the results of the temporal congruence tests.

The performance of the mental chronometry and rotation tasks by the TBI patients in our study indicated a preserved ability to internally reproduce the motor action, although imagined movements were performed more slowly and less accurately. Brain imaging studies have shown that the premotor cortex, the prefrontal cortex, the posterior parietal cortex, the cerebellum and the basal ganglia are all involved in motor imagery. Dominey et al found motor imagery to be asymmetrically slowed in hemi-Parkinson patients, confirming that dysfunction of the basal ganglia not only affected motor execution but also the internal representation of motor sequences[14]. In a study of patients with unilateral cerebellar lesions, Battaglia et al observed a reduced ability to prepare and imagine sequential movements[12].

Since many brain areas involved in motor imagery, are frequently damaged in patients with a traumatic brain lesion, TBI is also expected to reduce motor imagery capacity. The present study confirms the reduced vividness of motor imagery in a TBI population, with a deterioration of temporal coupling and accuracy of motor imagery. Motor imagery training might help to improve the vividness of motor imagery and the internal representation of intended movements, and hence promote motor skills in this patient group.

Study Limitations

The heterogeneous nature of a TBI patient group makes it difficult to draw general conclusions from such a study. However, we attempted to address this by including only patients with a moderate to severe TBI as indicated by the coma and posttraumatic amnesia duration. Grouping of the TBI patients in this study was based on approximate MRI data. Further refining of lesion localization and extending the number of patients in each group according to pathology seem necessary to gain more insight into the influence of lesion localization on motor imagery ability in TBI.

Conclusions

The present findings indicate that, while TBI patients may still perform motor imagery, our cohort showed a decrease in the 3 motor imagery modalities, with a decrease of motor imagery vividness, temporal congruence and accuracy. Further research is important to evaluate if motor imagery training can improve the motor planning capacities of TBI patients and thus enhance their functional recovery.

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Figure Legends

Figure 1. Stimulus of the walking trajectory test.

Figure 2. Performance of traumatic brain injury patients and control subjects on the Time Dependent Motor Imagery Test.

Figure 3. Reaction times of different rotation angles for traumatic brain injury patients and control subjects on the hand mental rotation task.

Table 1 Participants' Characteristics

Characteristics	TBI patients (n = 20)	Control subjects (n = 17)
Sex (men:women)	16:4	13:4
Age (years)	31.2 ±12.3	32.1 ± 14.2
Education (years)	13.6 ±1.9	13.6 ± 2.4
Time since injury (months)	15.9 ± 9.5	NA
Range	3 – 33	NA
Coma duration (days)	18.8 ±13.3	NA
Range	2 - 49	NA
PTA duration (weeks)	6.3 ± 2.9	NA
Range	2-12	NA
Hemiplegia	9	NA
Right	4	NA
Left	5	NA

* TBI : traumatic brain injury ; † PTA : posttraumatic amnesia

Table 2 Description of Brain Injury Localization

TBI patient	Lesion localization
1	DAI
2	bifrontal contusion– DAI
3	bifrontal contusion– right temporal contusion – DAI
4	right frontal – temporo-occipital contusion
5	bifrontal – bitemporal contusion
6	bifrontal – right cerebellar contusion
7	left temporal contusion– DAI
8	right temporal contusion– DAI
9	left temporoparietal contusion
10	right temporal contusion
11	right frontal contusion
12	frontotemporal contusion– cerebellar contusion
13	right frontoparietotemporal contusion – DAI
14	brainstem contusion
15	DAI
16	right frontoparietotemporal contusion
17	bifrontal contusion – DAI
18	right frontal contusion – DAI
19	unknown
20	bitemporal contusion– DAI

* TBI : traumatic brain injury ; † DAI : diffuse axonal injury