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6 Motor Imagery Ability in Patients with Traumatic Brain Injury

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26 ABSTRACT Motor imagery ability in patients with traumatic brain injury

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

29 **Design:** Prospective, behavioral study with matched control subjects

30 **Setting:** Rehabilitation unit in a university hospital

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

33 **Interventions:** not applicable

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

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

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

50 Key words : Traumatic brain injury; Motor imagery; Rehabilitation

- 51 List of abbreviations :
- 52 MIQ Movement Imagery Questionnaire
- 53 MIQ-R Movement Imagery Questionnaire- revised
- 54 MIQ-RS Revised version of the MIQ-R
- 55 TDMI Time Dependent Motor Imagery
- 56 TBI Traumatic Brain Injury
- 57 CTL Control
- 58

59 Motor imagery is the imagining of an action without its actual execution. It is a process
60 during which the representation of an action is internally reproduced within the working
61 memory without any overt output¹. Mental practice can be described as a cognitive process in
62 which movements are repeatedly mentally simulated without any overt body movement².

63 There is evidence that mental practice as an additional therapy has effects on motor recovery
64 after damage to the central nervous system. Since mental practice based on motor imagery is
65 not dependent on residual motor function, it can be used in neurological rehabilitation to train
66 the more cognitive aspects of motor tasks and thus improve physical recovery²⁻⁸. However,
67 before starting mental practice, it is imperative to assess whether the patient is still able to
68 engage in motor imagery⁹. Unrelated to cerebral damage, there are individual differences in
69 motor imagery ability. Hall et al¹⁰ classified subjects as high or low imagers based on their
70 Movement Imagery Questionnaire (MIQ) scores. They demonstrated that individual
71 differences in motor imagery ability can influence motor task performance, with high imagers
72 reproducing movements more accurately than low imagers¹¹. Moreover, since motor imagery
73 and motor execution are believed to share a similar underlying neural network, any structural
74 damage to the brain could affect both motor performance and motor imagery⁹. Therefore,
75 patients with impaired motor imagery ability should be identified before starting any imagery
76 therapy. Motor imagery ability has already been assessed in several clinical populations.

77 Individuals with motor impairments due to brain lesions caused by stroke, cerebral palsy or
78 Parkinson's disease, seem to show only partially preserved motor imagery capacities¹²⁻¹⁷.

79 We will assess motor imagery ability in patients with a moderate to severe head injury using
80 MIQs, a mental chronometry paradigm and mental rotation tasks¹⁸. MIQs measure the
81 vividness of motor imagery¹⁹. Subjects are asked to indicate the ease with which they are able
82 to imagine a certain movement. Several studies indicate that ratings from imagery
83 questionnaires provide a good indication of the ability to generate vivid images of

84 movements^{10,19-22}. The MIQ-revised (MIQ-R) is a self-report questionnaire, developed by
85 Hall et al, to assess visual and kinesthetic modalities of movement imagery¹⁰. A revised
86 version, the MIQ-RS, was developed by Gregg et al²⁰ to measure the visual and kinesthetic
87 components of motor imagery ability in patients with motor impairments. The MIQ-RS is
88 composed of 2 subscales of 7 relatively simple movements, for use in people with limited
89 mobility, e.g. bending forward or pulling a door handle.

90 Mental chronometry paradigms measure the temporal coupling between actual and imagined
91 movements. Several investigators have demonstrated that it takes a similar amount of time to
92 imagine and execute an action²³⁻²⁵. The match between imagined and actual movement times
93 indicates a reliable use of motor imagery. Malouin et al confirmed the reproducibility of the
94 temporal congruence test and the Time Dependent Motor Imagery (TDMI) screening test for
95 measuring the temporal behavior of motor imagery in healthy subjects and persons
96 poststroke²⁵. We also introduced a walking trajectory test to quantify imagery of gait. This
97 test, which was developed by Bakker et al., demonstrated a high temporal congruence
98 between actual and imagined walking in a healthy population²³.

99 Finally, mental rotation tasks, which measure implicit motor imagery ability and accuracy, are
100 based on the fact that the mental rotation time of a picture depends on the angular rotation of
101 that picture²⁶. Moreover, using bodily stimuli, the mental rotation time follows the
102 biomechanical constraints, in that biomechanically more difficult orientations result in slower
103 reaction times²². In our study, we used a hand mental rotation test that was a two-dimensional
104 variant of Parsons's hand laterality test, with imagined movement times measured without
105 subjects making a left-right judgment²⁷.

106 To our knowledge, motor imagery ability in persons with a moderate to severe traumatic brain
107 injury (TBI) has not been investigated. The present study was primarily designed to examine
108 motor imagery ability in patients with a moderate to severe TBI, using an MIQ, mental

109 chronometry paradigms and a mental rotation task. If motor imagery ability is at least
110 partially preserved in these patients, then this cohort could potentially benefit from motor
111 imagery training in the future.

112

113 **Methods**

114

115 Study Design and Participants

116

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

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

124

125 Measures

126

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

134 *Time Dependent Motor Imagery screening test.* For the TDMI test, the subjects were seated
135 on a chair and were instructed to imagine stepping movements over varying time periods. The
136 stepping movement consisted of placing one foot forward on a board and then placing it back
137 on the floor. First, the examiner demonstrated the movement and then the subjects were
138 instructed to actually perform the movement physically twice. During the imagery task, the
139 subjects were asked to close their eyes and to count each time they imagined touching the
140 board. Each subject completed 3 trials. Each trial terminated after a varying time period of 15,
141 25 and 45 seconds. The examiner recorded the number of imagined movements in these 3
142 time periods.

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

147 *Walking trajectory test.* For this test, the subjects were seated in a chair in front of a computer
148 screen that displayed photographs of 3 walking trajectories (Figure 1). The walking
149 trajectories had a varying length of 2, 5, and 10 m. The beginning of the walking trajectory
150 was marked with a blue line, the end with a cone. There were 2 practice sessions, an imagery
151 session and an actual walking session. Each imagery session started with the presentation of a
152 photograph of a walking trajectory. The subjects were then asked to close their eyes and to
153 imagine walking along the path. The examiner recorded the duration of each trial.

154 Subsequently, the subjects performed the actual walking trial. The actual walking session was
155 always performed after the imagery session to minimize the amount of tacit knowledge about
156 the time it actually takes to walk along the trajectory.

157 *Hand mental rotation test.* The subjects were seated on a chair, facing a computer screen that

158 displayed photographs of left and right hands. The hands were presented in varying two-
159 dimensional orientations of 30°, 60°, 90° and 120°. Stimuli were presented in a random order.
160 The subjects were instructed to imagine moving their hands from the upright position, palm
161 down, to the position of the stimulus hand and to press the enter button as they completed
162 their imagined action.

163

164 Statistical Analysis

165

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

174

175 Results

176

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

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

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

187 A repeated measures analysis of variance of the TDMI data with time period (15s, 25s, and
188 45s) as within-subject factor and group (TBI, CTL) as between-subject factor disclosed a
189 significant main effect of time period with increasing imagined steps over longer time periods
190 ($F_{2,34} = 153.5$, $P<.001$). A significant main effect of group revealed less imagined stepping in
191 the TBI group ($F_{1,35} = 15.5$, $P<.001$), and a significant period by group interaction effect
192 showed that this difference increased with longer time periods ($F_{2,34} = 10.6$, $P<.001$). This
193 interaction effect is depicted in Figure 2.

194 The temporal congruence stepping test scores revealed a statistically significant correlation
195 between imagined stepping time and actual stepping time in both groups (TBI group, $r=0.82$,
196 $P<.001$ and CTL group, $r=0.80$, $P<.001$). We found no statistical differences in the actual
197 stepping/imagined stepping ratio between the two groups.

198 A repeated analysis of variance was performed to analyse the walking trajectory test with
199 condition (executed, imagined) and distance (2m, 5m, 10m) as within-subject factors and
200 group (TBI, CTL) as between-subject factors. A significant main effect of condition showed
201 longer durations for the imagery conditions ($F_{1,35} = 17.4$, $P<.001$), and a significant main
202 effect of distance revealed longer distances leading to longer performance times ($F_{2,34} = 81.8$,
203 $P<.001$). A significant main effect of group showed consistently longer response times for the
204 TBI group ($F_{1,35} = 9.9$, $P = .003$). Significant condition by group, and distance by group
205 interaction effects showed that the TBI patients took relatively longer over the imagery
206 conditions and over longer trajectories than the CTL group, $F_{1,35} = 8.9$, $P = .005$ and $F_{2,34} =$
207 6.8 , $P = .003$, respectively. A strong relationship between imagined and actual walking times

208 was found in both groups (TBI: 10m, $r = .65$, $P = .004$; CTL: 10m, $r = .61$, $P = .005$), but the
209 actual walking time/ imagined walking time ratio was significantly increased in the TBI group
210 ($T_{35} = -2.26$, $P = .03$). Further analysis revealed a significantly higher ratio (worse
211 performance) in patients with frontal brain damage compared to patients with other lesion
212 localizations ($T = 2.19$, $P = .04$) and a significantly higher ratio (better performance) in patients
213 with diffuse axonal injury ($n = 10$) compared to those with predominantly cortical damage (n
214 $= 9$, $T = -2.8$, $P = .01$).

215 The results of the hand mental rotation test indicated a statistically significant main effect of
216 rotation angle on imagined movement times with increasing angles resulting in increasing
217 movement times ($F_{3,33} = 17.0$, $P < .001$). A main effect of group was also obtained showing a
218 significantly slower execution of the imagined hand rotations in the TBI group ($F_{1,35} = 5.8$,
219 $P = .02$). We found no group by angle interaction effect. These effects are illustrated in Figure
220 3.

221

222 **Discussion**

223

224 The present study was designed to assess motor imagery ability in patients with a moderate to
225 severe TBI. Before starting mental practice in neurological rehabilitation, it is necessary to
226 establish whether patients are still able to imagine movements and thus benefit from motor
227 imagery training. We used questionnaires, mental chronometry and mental rotation tasks to
228 study motor imagery abilities in adults with TBI. The results achieved in our study cohort
229 provide evidence that the ability to internally represent movements is preserved after TBI but
230 motor imagery is less vivid and less accurate, with imagined movements performed more
231 slowly than actual movements. To our knowledge, this study is the first to assess the
232 vividness of motor imagery in TBI patients. The visual and kinesthetic scores of the MIQ-RS

233 were lower in the patient group compared to the healthy control subjects. These results appear
234 to conflict with those of studies investigating motor imagery ability after stroke. Malouin et al
235 found the vividness of mental images after stroke to be similar to that in age-matched control
236 subjects. However, motor imagery ability was not symmetrical, with an overestimation when
237 imagining limb movements of the unaffected side¹⁶. Relying on the subjects' self report ,
238 Kimberly et al found no difference in motor imagery ability between subjects with stroke and
239 healthy control subjects²⁹. The dominance of visual motor imagery, usually observed in
240 healthy adults, was not confirmed in the present study. Possibly, the use of an adapted scale
241 with relatively simple motor tasks influenced the ease with which the kinesthetic component
242 of the imagery task was performed.

243 The TDMI, the temporal congruence test and the walking trajectory test have been
244 standardized and their test-retest reliability has been confirmed²⁵. The results of the present
245 study support the relevance of these mental chronometry tests for use in a population
246 requiring neurological rehabilitation. Imagined/actual movement time ratios offer a means to
247 quantify the changes in the temporal characteristics of motor imagery. In all mental
248 chronometry tasks, a significant correlation was found between executed and imagined
249 movement times in both the TBI and the CTL group. In all tasks, however, the
250 imagined/actual movement time ratios were significantly increased in the TBI group,
251 indicating a temporal uncoupling between actual and imagined movements. These results are
252 consistent with the findings of other studies. Malouin et al reported increased
253 imagined/executed movement time ratios in patients with stroke²⁵ and Caeyenberghs et al,
254 who investigated motor imagery ability in children with brain injury, found an inferior ability
255 to imagine the time needed to complete goal-directed movements³⁰.

256 Johnson et al found no evidence that chronic limb immobility after stroke compromised the
257 ability to internally plan movements of the paretic arm. In their study, both groups performed
258 at a comparable high level of accuracy on a mental rotation task³¹.

259 We also investigated the relationship between the different motor imagery measures and
260 found no correlation between the results of the imagery questionnaires and those of the mental
261 chronometry tasks in either group. Possibly, anosognosia, a disturbance of self-awareness,
262 limits the usefulness of these self-report questionnaires in a brain-injured patient group since
263 many patients underestimate the severity of their cognitive functioning deficits^{32,33}. Moreover,
264 as shown in Table 2, many patients had frontal lobe damage, which is known to be involved
265 in anosognosia pathogenesis³³. The present study showed that patients with frontal lobe
266 damage had difficulties in assessing their motor imagery ability with overrated scores of the
267 MIQ-RS, compared to the results of the temporal congruence tests.

268 The performance of the mental chronometry and rotation tasks by the TBI patients in our
269 study indicated a preserved ability to internally reproduce the motor action, although
270 imagined movements were performed more slowly and less accurately. Brain imaging studies
271 have shown that the premotor cortex, the prefrontal cortex, the posterior parietal cortex, the
272 cerebellum and the basal ganglia are all involved in motor imagery. Dominey et al found
273 motor imagery to be asymmetrically slowed in hemi-Parkinson patients, confirming that
274 dysfunction of the basal ganglia not only affected motor execution but also the internal
275 representation of motor sequences¹⁴. In a study of patients with unilateral cerebellar lesions,
276 Battaglia et al observed a reduced ability to prepare and imagine sequential movements¹².

277 Since many brain areas involved in motor imagery, are frequently damaged in patients with a
278 traumatic brain lesion, TBI is also expected to reduce motor imagery capacity. The present
279 study confirms the reduced vividness of motor imagery in a TBI population, with a
280 deterioration of temporal coupling and accuracy of motor imagery. Motor imagery training

281 might help to improve the vividness of motor imagery and the internal representation of
282 intended movements, and hence promote motor skills in this patient group.

283

284 Study Limitations

285

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

293

294 Conclusions

295

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

301

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386 Figure Legends

387

388 Figure 1. Stimulus of the walking trajectory test.

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

391 Figure 3. Reaction times of different rotation angles for traumatic brain injury patients and
392 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