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MOTOR PERFORMANCE IN PHYSICALLY WELL-RECOVERED MEN WITH TRAUMATIC BRAIN INJURY

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Objective: **The primary aim of this study was to compare the motor performance of physically well-recovered men with traumatic brain injury with that of healthy men.**
Design: **Cross-sectional study in a national rehabilitation centre.**
Methods: **Static and dynamic balance, agility and rhythm co-ordination of men with traumatic brain injury ($n = 34$) and healthy controls ($n = 36$) were assessed. Between-group differences in dynamic balance and agility were analysed by analysis of covariance and differences in static balance and rhythm co-ordination by logistic regression analysis. Cut-off points for clinical screening were determined by receiver operating characteristics analyses.**
Results: **Men with traumatic brain injury had impaired balance and agility compared with healthy men and in a rhythm co-ordination test they had difficulties in starting and sustaining simultaneous rhythmical movements of hands and feet. In receiver operating characteristics analyses a running figure-of-eight test (agility), tandem walking forwards (dynamic balance) and rhythm co-ordination test with fast tempo were found the most sensitive and specific for distinguishing between men with traumatic brain injury and the healthy men.**
Conclusions: **The impairments in motor performance of physically well-recovered patients with traumatic brain injury were obvious. The results of this study extend the knowledge of problems in motor performance among patients with traumatic brain injury and provide further information for clinical rehabilitation.**

Key words: brain injury, motor skills, psychomotor performance, rehabilitation.

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INTRODUCTION

Traumatic brain injury (TBI) is a worldwide public health problem (1). The incidence of hospitalized patients with TBI in the USA has been 618 cases/100,000 person years (py), in Southern Australia 322 cases/100,000 py and in Scotland 326 cases/100,000 py (2–4). According to Sosin et al. (3) only 25% of all TBI cases are treated in hospitals. The number of new hospitalized TBI cases in Finland has been 100/100,000 py (5).

TBI is known to cause a diversity of disorders, involving motor performance, behavioural, emotional and cognitive symptoms. Cognitive and behavioural deficits resulting from TBI have been well documented, but this is not the case for the physical symptoms in terms of moderate or mild TBI. In conventional neurological examinations the findings may often be normal, but the patients still complain of undefined symptoms. These subjectively experienced symptoms may arise when patients are returning to pre-morbid activities, sport or work (6–8).

Impaired balance and altered co-ordination are common complaints (9, 10). From a clinical point of view, many patients with TBI have difficulties in tasks requiring simultaneous rhythmic movements of the upper and lower limbs compared with uninjured counterparts (11). In terms of physical problems after mild or moderate TBI, it has been considered important to identify rapid alternating movements, gait and balance, static/dynamic posture and vestibular system integrity (8).

So far, no widely accepted standardized motor performance screening tests for adult patients with TBI are available for clinical use. Even with the problems in motor performance that are observed clinically, it is not clear how to assess motor performance among physically well-recovered patients with TBI. The primary aim of this study was to compare the motor performance of physically well-recovered men with TBI with a control group of healthy men. The secondary aim was to establish sensitive, specific and valid cut-off values of respective motor performance measures for clinical use.

MATERIAL AND METHODS

Subjects

Voluntary male patients with TBI who consecutively attended a nationwide rehabilitation centre (Käpylä Rehabilitation Centre, Helsinki, Finland) and who fulfilled the inclusion criteria of the study were recruited between March 2001 and March 2002. In total, 41 subjects with TBI were interviewed on the first day of their rehabilitation period to ensure compatibility for the study. Healthy men of similar age and years of education as the subjects with TBI served as controls. The inclusion criteria for all the subjects were: (*i*) age 19–55 years; (*ii*) body mass index (BMI) less than 35; (*iii*) passed Mini Mental State Examination (MMSE; normal >24/30), which is a widely used method for assessing cognitive status in adults, testing orientation, attention, immediate and short-term recall, language, and ability to follow simple verbal and written commands (12); and they were able (*iv*) to maintain initial test positions; (*v*) to perform a 2 km Walk Test developed at UKK Institute (13); and (*vi*) to run a short distance. In addition, for the subjects with TBI, more than one year should have passed since the

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injury. To determine the eligibility for the study the type and time of the injury were verified from medical files. In addition, Glasgow Coma Scale (GCS) scores (the worst score during the first 24 hours at acute hospital admission) were also re-examined and radiological (computed tomography (CT)/magnetic resonance imaging (MRI)) findings were evaluated by a neurologist from medical files. The subjects were interviewed about the length of post-traumatic amnesia (PTA). Of the patients with TBI, 2 refused to participate in the study and 5 were excluded due to the inclusion criteria. In total, 34 men with TBI (mean age 34 years) and 36 healthy controls (mean age 31 years) met the inclusion criteria. All participants gave their informed consent. A description of subjects is given in Table I. The study was approved by the Ethics Committee for Ophthalmology, Otorhinolaryngology, Neurology and Neurosurgery of the Helsinki and Uusimaa Hospital District.

Test protocol

A pre-test health screening was conducted according to the safety model of the UKK health-related fitness test battery for adults, which included a modified version of the physical activity readiness questionnaire (MPAR-Q) (14) and questions on current and past physical activity.

The test battery consisted of 5 tests: 1 for static balance (14), 2 for dynamic balance (14, 15), figure-of-eight running test for agility (16) and a test for rhythm and co-ordination with slow and fast tempo (15). The tests were carried out in a silent environment, on a flat surface with enough space, at least 15 metres, for moving. All tests were performed with shoes on. Each test session lasted approximately 30 minutes. Subjects were instructed not to smoke 30 minutes before the test session, not to be under the influence of alcohol during testing, and to avoid stimulants, such as coffee, tea, etc., one hour before testing. Before starting, the tester explained and demonstrated the performance of each test and the subjects were allowed to practice it once.

Test procedure

Static and dynamic balance.

Balancing on 1 leg (14). In order to measure static balance subjects stood on 1 leg with their eyes open and arms relaxed by their sides. They placed the heel of the opposite foot against the medial side of the supporting leg at the level of the knee joint, and kept the thigh rotated outwards. Static balance time was measured with a stopwatch in seconds, and the uppermost limit for the trial was 60 seconds. If this limit was not reached during the first trial, a second trial was allowed. The best of 2 trials was used in the statistical analyses. The test was performed separately on both legs, starting on the right leg.

Tandem walking forwards (15). In order to measure dynamic balance, the subjects were instructed to place one foot in front of the other with the heel and toe of their shoes touching (tandem step), and walk as fast as possible along a line 6 metres long without side touches or mistakes in tandem steps. The test was performed 3 times and the walking time of each trial was measured in seconds. The best result of 3 trials was used in the analyses.

Tandem walking backwards (14). The instructions and the conditions were the same as for tandem walking forwards, but the walking direction was backwards. The best result of 3 trials was used in the analyses.

Agility.

Running in a figure-of-eight (16). The subjects were asked to run as fast as possible a course in a figure-of-eight. The course was marked with 2 traffic cones placed 10 metres apart with the start/finish line next to one of the cones, the total length of the course being 20 metres. The stopwatch was started concurrently with the starting signal and was stopped when the subject completed the course and crossed the start/finish line again. The time was recorded in seconds. This test procedure was in line with the original test procedure but in this study subjects were asked to run the course only once in each trial. On the whole, the test was performed 3 times with a short resting period between each trial. The best result of 3 trials was used in the analyses.

Rhythm and co-ordination.

Slow rhythm phase (15). The slow rhythm comprised 2 consecutive parts, each of 30 seconds duration, and the tester scored the

Table I. *Characteristics of subjects with traumatic brain injury (TBI) and control group, mean values with standard deviation (SD) of the performance in tandem walking tests and running in a figure-of-eight and proportion (%) of unsuccessful/successful test performance in balance and rhythm co-ordination tests*

	TBI group ($n = 34$)	Control group ($n = 36$)
Age (years; mean (SD))	34 (10)	31 (11)
Height (cm; mean (SD))	177 (7)	178 (8)
Weight (kg; mean (SD))	80 (15)	79 (13)
Months since trauma (median)	24	–
Length of education (n)		
9 years	7	6
10 years	1	1
12 years	26	29
Post-traumatic amnesia (n)		
Mild (<24 hours)	1	–
Moderate (1–7 days)	7	–
Severe (>7 days)	10	–
Very severe (>4 weeks)	15	–
Unknown	1	–
Glasgow Coma Scale score*		
Mild (13–15)	10	–
Moderate (9–12)	1	–
Severe (3–8)	15	–
Brain CT/MRI findings (n)		
Contusion and/or intracranial haematoma	26	–
Diffuse axonal injury	5	–
Signs of severe intracranial pressure	4	–
Neurosurgical treatment		
Craniotomy	2	–
Type of rehabilitation after injury (n)		
Outpatient		
Neuropsychological rehabilitation	24	–
Physical therapy	14	–
Speech therapy	3	–
Occupational therapy	4	–
Inpatient rehabilitation	6	–
Subjectively perceived motor deficiencies in sport activities (n)		
Defects in balance	8	–
Clumsiness in arm movements	3	–
Difficulties in running	6	–
Fatigue	6	–
Weekly exercise or sport activities (times)		
None	10	3
Once or twice	6	5
Three times or more	20	25
Weekly leisure time physical activities (times)		
None	1	1
Once or twice	19	13
Three times or more	14	22
2 km Walk Test		
Walking time (minutes:seconds; mean, (SD))	18:49 (2:16)	17:24 (2:00)
Mean performance times of tests (seconds; mean, (SD))		
Tandem walking forwards	14.9 (4.3)	11.3 (2.8)
Range	9.3–28.5	6.3–20.3
Tandem walking backwards	17.6 (6.3)	14.0 (4.3)
Range	10.0–37.2	9.0–27.0
Running in figure-of-eight	8.4 (2.1)	6.6 (0.5)
Range	6.2–15.6	5.6–7.6

Table I (*Continued*)

	TBI group (n =34)	Control group (n =36)
Proportion of unsuccessful/successful performance		
Balance on 1 leg (%)	44/56	14/86
On the right leg (<60 seconds/ 60 seconds)		
On the left leg (<60 seconds/ 60 seconds)	50/50	8/92
Rhythm co-ordination (%)		
Slow rhythm (0–6 points/ 7–8 points)	65/35	31/69
Fast rhythm (0–6 points/ 7–8 points)	65/35	28/72

*Glasgow Coma Scale scores were registered at acute hospital phase in 26 patients' medical files; registration was missing in 8 patients files.

performance of each part in points. At the start the subject was asked to march on the spot in accordance with a metronome signal (M =92 beats/min), one step for every single beat for 30 seconds. After that the subject was asked to continue marching for another 30 seconds and to clap his hands together on every other beat. Points were given for both parts separately according to: (*i*) accuracy in the first 10 seconds: 0 = totally asynchronous marching, 1 =getting in the marching rhythm gradually during the first 10 seconds, 2 =synchronous marching rhythm at first go; and (*ii*) maintenance of the exact rhythm from 10 to 30 seconds: 0 =totally asynchronous rhythm co-ordination while marching and clapping, 1 =difficulties in keeping to the rhythm, 2 =maintaining accurate marching and clapping rhythm for rest of the test. In consequence, the sum of these scores in the slow rhythm phase was 0–8 points, which was used in the analyses.

Fast rhythm phase (15). The fast rhythm phase started immediately after the slow phase when the tester had set the metronome to a fast rhythm (M =138 beats/min), otherwise the same procedure was repeated to the rhythm of the metronome. The sum of the scores in the fast rhythm phase was also 0–8 points which was used in the analyses.

Both slow and fast rhythm phases were performed only once.

Statistical methods

The means and standard deviations (SD) are presented as descriptive statistics. In the dynamic balance tests and agility test the between-group differences were analysed by analysis of covariance (ANCOVA) adjusted for age. Logistic regression analysis was used for analysing the group differences in static balance and sense of rhythm tests. In the analyses the results of these tests were used as dichotomous dependent variables, the group variable as independent variable and age as covariate. For the analysis the results of the static balance tests were dichotomized into categories of 60 seconds and below 60 seconds. In the rhythm co-ordination tests a dichotomous variable was formed according to the accuracy of the test: "synchronous movements" 7 or 8 points, "asynchronous movements" 0–6 points. Age-adjusted odds ratios (OR) and their 95% confidence intervals (CI) were calculated.

In order to find the abnormalities in motor performance caused by TBI receiver operating characteristics (ROC) analyses were performed. On the basis of the ROC analyses cut-off values were determined and calculated for all tests with their respective sensitivity and specificity to distinguish "normal" from "abnormal" performance. The ROC analysis evaluates the general performance of the measures and describes the clinical performance of screening tests in terms of diagnostic accuracy: The true positive rate (sensitivity) is plotted against the false positive rate (1–specificity). The area under the curve (AUC) in the ROC analysis generally assesses the discriminatory power of the test. The AUC can take values between 0 and 1 where an AUC of 1 is a perfect screening test and 0.5 represents a test equal to chance. In the ROC curve diagrams, a 45° line was plotted representing an AUC of 0.5. The perfect cut-off point is in the upper left corner of the graph. For clinical use the point closest to this was considered to be the optimal cut-off value to minimize misclassifications (17, 18). All statistical analyses were performed using SPSS software, version 12.0.1 (SPSS INC, Chigago IL, USA).

RESULTS

The study population is described in Table I. The subjects in the TBI group were slightly older than the controls (mean age 34 vs 31 years) which was taken into consideration in the analyses. In the TBI group 55% (19 men) had medical treatment for sleeping or mood problems or pain. Only 3 men in the control group had medication, 2 for allergy and one for asthma. No other remarkable between-group differences were seen in the background characteristics. Overall, 79% (24 men) of the TBI group reported that they have had to change their sport activities after injury and 4 men of TBI group had totally quitted their former sport activities. Subjectively experienced deficiencies are presented in more details in Table I.

Static balance was measured by standing both on the right and on the left leg. As the result of logistic regression analysis, the TBI group had poorer static balance than the controls (OR of the right leg for poor performance (below 60 seconds) 4.6, 95% CI 1.4–15.3; OR of the left leg 10.7, 95% CI 2.7–43.6, respectively). Nearly half of the TBI group were unable to maintain their balance on one leg (44% on the right, 50% on the left leg) for 60 seconds. However, only 14% of the controls did not reach the uppermost limit in static balance test on the right leg and 8% on the left leg.

The means and SD of the dynamic balance and agility tests are also shown in Table I. The TBI group performed both 6 metres of tandem walking forwards and backwards statistically significantly more slowly than the control group. The age-adjusted mean differences between the study groups were 3.3 seconds in the tandem walking forwards (95% CI 1.6–4.9; p =0.001; ANCOVA) and 3.2 seconds in walking backwards (95% CI 0.7–5.8; p =0.014). In the agility test the TBI group running a figure-of-eight was statistically significantly slower than in the control group, the mean difference being 1.7 seconds (95% CI 1.0–2.4; p <0.001). In addition, the range of test results was wider among the subjects with TBI than in controls in all tests involving motion.

The age-adjusted OR for arrhythmic (0–6 points in test) co-ordination was 4.3 (95% CI 1.3–13.9) when comparing the TBI group with the controls. In the slow rhythm co-ordination test 41% of the subjects in the TBI group had difficulties in starting or/and maintaining the given rhythm. However, only 14% in control group performed the test inaccurately. At fast rhythm 62% of the men in the TBI group had difficulties with rhythm co-ordination, whereas 22% of the controls had asynchronous performance (OR 7.3; 95% CI 2.3–23.6).

Sensitivity, specificity, cut-off points and the AUC for each test are given in Table II. The ROC curves for the both tandem

Table II. *Receiver operating characteristic (ROC) curve areas and cut-off points for tandem walking forwards and backwards, agility, balancing on one leg and rhythm co-ordination tests with their respective sensitivity and specificity to distinguish men with traumatic brain injury (TBI) from healthy subjects*

Test	Area under curve (95% CI)	Cut-off point	Sensitivity (%)	Specificity (%)
Tandem walking forwards	0.76 (0.65–0.88)	≥13.0 seconds	70.6	77.8
Tandem walking backwards	0.70 (0.57–0.82)	≥16.0 seconds	55.9	77.8
Running in figure-of-eight	0.86 (0.78–0.95)	≥7.2 seconds	73.5	86.1
Balancing on 1 leg (max. 60 seconds)				
On the right leg	0.65 (0.52–0.78)	≤59 seconds	44.1	86.1
On the left leg	0.71 (0.59–0.84)	≤55 seconds	50.0	91.7
Rhythm co-ordination (max. 8 points)				
Slow rhythm	0.70 (0.57–0.82)	≤7 points	64.7	69.4
Fast rhythm	0.75 (0.63–0.86)	≤6 points	61.8	77.8

Area under curve reflects the probability that a random person with TBI has a higher value of measurement than a random person without TBI. The optimal cut-off point for identifying the TBI patients. Sensitivity: true positive rate. Specificity: 1-false positive rate.

walking tests and running the figure-of-eight test are presented in Fig. 1A, for balancing on one leg in Fig. 1B and rhythm co-ordination in Fig. 1C. In the agility test (running the figure-of-eight) 56% of the men in the TBI group performed the test more slowly than the controls. The probability of detecting problems in motor performance caused by TBI was best in this test; the AUC value was the highest at 0.86. Accordingly, the determined cut-off point of 7.2 seconds had the highest sensitivity and specificity of all tests used in this study, 74% and 86%, respectively.

The AUC values in other motor performance tests were fairly high, varying from 0.70 to 0.76, except in the balancing test on the right leg. Of dynamic balance tests the tandem walking forwards and the test for fast rhythm also had good sensitivity and specificity.

DISCUSSION

In the present study we assessed the motor performance of the physically well-recovered men with TBI in terms of agility, balance and rhythm co-ordination, which was clearly impaired compared with the control group. The subjects with TBI performed the figure-of-eight running and tandem walking tests statistically significantly more slowly than the control group and had difficulties in co-ordinating simultaneous hand and foot movements in a given rhythm. Due to these differences the ROC curves and cut-off values with their respective sensitivity and specificity proved to be relevant.

These deficits may be partly explained by reduced velocity due to TBI. Basford et al. (10) performed a three-dimensional motion analysis of self-selected walking speed and balance among patients with TBI and healthy subjects. The patients with TBI were found to have significantly lower body centre of mass displacement and velocities in anterior–posterior direction than the healthy controls, whereas the mediolateral movements were larger, both reflecting reduced walking velocity. In our study the patients with TBI had also difficulties in maintaining static balance both on the right and left leg, some of them could stand only a few seconds on one leg. These findings are in line with the study by Geurts et al. (19), where they observed patients with TBI standing quietly on both feet and a weight shifting task on a dual-plate force platform.

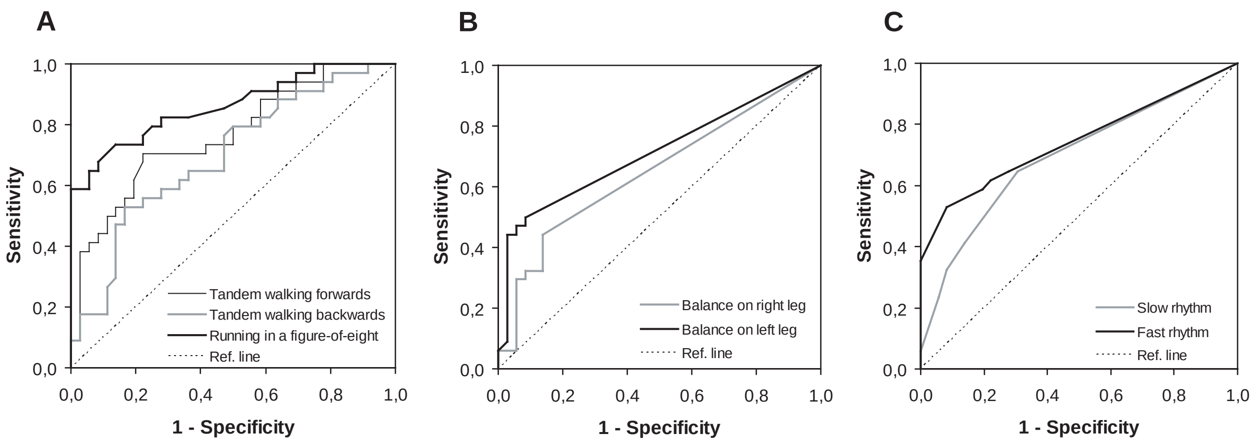

Fig. 1. Receiver operating characteristic (ROC) curve analyses of sensitivity and specificity for determining the optimal cut-off point to distinguish "normal" performance from "abnormal". (A) Tandem walking forwards, tandem walking backwards and figure-of-eight running tests. (B) Balancing on the right leg and on the left leg tests. (C) Slow and fast rhythm co-ordination tests. The broken line represents a test equal to chance (area under curve = 0.5). All the performance tests distinguished the men with TBI from the healthy men statistically significantly better than by chance ($p < 0.05$).

Furthermore, in our study, simultaneous marching and hand clapping to a given rhythm proved to be a more difficult task for patients with TBI than the controls. The subjects had difficulties while performing the slow rhythm, but the fast rhythm co-ordination task revealed even more problems compared with the healthy controls. Our results were consistent with those reported by Azouvi et al. (11), who described slowed information processing in dual-tasks test and even more difficulties in a high time-pressure in laboratory setting.

Because the differences between the TBI and control groups were statistically significant, it was important to determine the cut-off points with the best sensitivity and specificity for clinical use. The figure-of-eight running, fast rhythm co-ordination and tandem walking forwards tests were the best for screening out men with TBI from healthy controls. In the same way, the specificity of the static balance test was high, but sensitivity remained low due to the ceiling effect of the uppermost limit of 60 seconds: most of the controls were able to stand on one leg for the whole minute.

In rhythm co-ordination the first analyses of differences between the groups was based on an assessment used earlier among healthy middle-aged men and women (15). In this study the cut-off points were determined more precisely for clinical use according to the ROC analyses, which gives a more exact evaluation. In the fast phase rhythm co-ordination 6 points became the cut-off having higher sensitivity and specificity than cut-off at 7 points, which is used in logistic regression analysis. However, the between-group differences both in slow and fast rhythm were already found at 7 points.

The motor performance items, which were the objects of our study, were also listed as items of the most obvious problems resulting from TBI and considered to be included for formal assessment (8). Moreover, it is probable that similar diffuse deficiencies in motor performance may be observed in patients with other diagnoses than TBI, e.g. patients with different types of stroke or patients using drugs affecting motor performance. In our study the subjects with TBI described their subjectively perceived of motor deficiencies as defects in balance, difficulties in running, clumsiness in arm movements and fatigue. The results of static and dynamic balance, figure-of-eight run and rhythm tests were in accordance with those descriptions, even though the gross motor clinical neurological examinations had not revealed the deficiencies. Even if the need for knowledge and tests measuring motor performance of physically well-recovered patients with TBI is recognized, only a few earlier studies have been aiming to explore these aspects (10). The tests used in this study are easy to administer in a clinical environment and constitute a test battery measuring different aspects of motor performance.

However, it should be noted that this study was conducted among men, and generalization to women concerning assessment of motor performance should be made with caution. In general, men are at greater risk of even mild TBI, the risk for men being 0.88–2.5 times higher than the risk for women (1, 20). In our study, the men with TBI were, on admission to acute hospitals after the accident, rather heterogeneous with respect to a large variation of GCS scores (range 3–15) and different types of CT/MRI findings. After the acute phase, most of the TBI subjects had also been in outpatient rehabilitation. When the TBI subjects attended to Käpylä Rehalitation Centre and participate to this study, at least one year had passed since the injury. On whole, the TBI subjects seemed to be recovered physically well and were consistent with the inclusion criteria, but the representativeness of the results is limited due to small sample size. Nevertheless, the number of subjects was sufficient for reliable statistical analyses and the results can be interpreted indicatively.

In conclusion, the results established that deficiencies in the motor performance of physically well-recovered patients with TBI disturbing pre-morbid activities can be detected in clinical practice. The usefulness and validity of the test battery should be investigated in larger prospective studies. Further research is needed to compare different subgroups of TBI patients, in order to determine and to evaluate the precise effects of TBI rehabilitation on motor performance.

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