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Measurement Properties of the High-Level Mobility Assessment Tool for Mild Traumatic Brain Injury

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Background. The High-Level Mobility Assessment Tool (HiMAT) was developed to quantify balance and mobility problems after traumatic brain injury (TBI). Measurement properties of the HiMAT have not been tested in the mild TBI (MTBI) population.

Objective. The aim of this study was to examine the reliability, validity, and responsiveness of the HiMAT in a sample of the MTBI population.

Design. A cohort, pretest-posttest, comparison study was conducted.

Methods. Ninety-two patients (69% men, 31% women) with a mean age of 37.1 years (SD=13.8) and a mean Glasgow Coma Scale score of 14.7 (SD=0.7) were recruited from Oslo University Hospital. All patients were tested with the HiMAT (range of scores=0 [worst] to 54 [best]) at 3 months postinjury. Fifty-one patients were retested at 6 months. A subgroup of 25 patients was selected for the reliability testing. Balance function reported on the Rivermead Post Concussion Symptoms Questionnaire was chosen as a criterion and anchor. Criterion-related validity was studied with correlation analysis. Intraclass correlation coefficients (ICCs) were used for assessing interrater and intrarater reliability. Minimal detectable change (MDC) for the HiMAT was estimated. Responsiveness was assessed with receiver operating characteristic curve analyses.

Results. The mean HiMAT sum score was 46.2 (95% confidence interval=44.4 to 48.1). The HiMAT had a ceiling effect of 22.8%. The correlation between HiMAT scores and self-reported balance problems was large ($r=-.63$, $P<.001$). Interrater and intrarater reliability of the HiMAT sum score was high (interrater ICC=.99, intrarater ICC=.95). The MDC was −3 to +4 points. Responsiveness was good, and the HiMAT discriminated well between patients with self-perceived improved balance function versus unchanged balance function (area under the curve=0.86).

Limitations. The small sample size, a ceiling effect, and lack of a gold standard were limitations of the study.

Conclusions. The HiMAT demonstrated satisfactory measurement properties for patients with MTBI. The HiMAT can be used as an outcome measure of balance and mobility problems in patients with MTBI.

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The incidence of episodes of hospital-treated traumatic brain injury (TBI) in Oslo, Norway, is 83.3/100,000, and 86% of these are classified as mild traumatic brain injury (MTBI) based on Glasgow Coma Scale (GCS) scores.[1] Balance problems are commonly reported symptoms following MTBI.[2–5] Balance is important in maintaining fluid dynamic movement and thereby affects mobility. *Balance* is defined as the ability to maintain the body's center of gravity within its base of support.[6,7] *Mobility* is defined as the ability to move safely and independently from one place to another.[7] Balance and mobility are strongly related constructs, and higher-level balance and mobility are required in physically demanding employment roles, social roles, and leisure and sporting activities.[6,8]

Due to the lack of instruments enabling the quantification of high-level mobility and balance in the TBI population, the High-Level Mobility Assessment Tool (HiMAT) for TBI was developed. It is an outcome measure for use in clinical work and research.[8–11] The HiMAT has shown high interrater reliability, retest reliability, and internal consistency in an Australian population of patients with moderate and severe TBI.[11] Its content validity and discriminability have been established, and the HiMAT has shown moderate concurrent validity, better responsiveness, and less ceiling effect than other measures of mobility.[8,10]

To our knowledge, the HiMAT has not been tested in the MTBI population. Such testing is important because the ceiling effect might be larger in a population with milder injuries and because other measurement properties of the HiMAT are not established for this large subgroup of patients. The HiMAT is a measure of high-level mobility skills, and it is expected that age, sex, and physical fitness will influence the outcome of the HiMAT score.[12] For the best possible interpretation of the HiMAT score, it is important to study the relationship between the HiMAT score and age, sex, and physical activity.

Traditionally used mobility assessment tools may not capture the experienced balance problems reported by patients with MTBI due to ceiling effects.[10,13,14] It is important, therefore, that instruments include high-level mobility items such as running and jumping, reflecting the various requirements of physical functioning.[9] Moreover, valid and reliable measures of balance and mobility for the MTBI population are important because they can assist the clinician in selecting appropriate therapy interventions and serve as outcome measures in clinical practice. It will be important, therefore, to explore whether the HiMAT is a valid and reliable measure of balance and mobility in the MTBI population.

The primary aim of the present study was to examine the validity, reliability, and responsiveness of the HiMAT in a sample of the MTBI population. The related research questions were: (1) Is the HiMAT a valid measure of balance and mobility in people with MTBI based on a criterion of self-reported balance problems? (2) Is the HiMAT a reliable measurement tool for patients with MTBI? and (3) Is the HiMAT a responsive measurement tool for patients with MTBI? The secondary aim was to study the impact of age, sex, and physical fitness on balance and mobility as measured by the HiMAT.

Method

Design

A prospective design was used. The included participants were tested with the HiMAT at a mean of 3.2 months (SD=1.2) after the injury and retested at a mean of 6.5 months (SD=0.7) after the injury. The mean time between the 2 tests was 3.2 months (SD=0.9). The study was conducted at the outpatient Department of Physical Medicine and Rehabilitation at Oslo University Hospital. Written informed consent was obtained from all participants prior to testing.

Participants

All participants were recruited at Oslo University Hospital from May 2008 to November 2010. At Oslo University Hospital, patients with MTBI are admitted to the Neurosurgical Department in the acute phase and receive follow-up 3 months postinjury at the outpatient clinic in the Department of Physical Medicine and Rehabilitation. They were included in the current study at the 3-month follow-up if they fulfilled the following criteria: age between 16 and 67 years and an MTBI defined by GCS score of 13 to 15[15] assessed immediately after head injury or at admission to the hospital. Exclusion criteria were: severe psychiatric disease, insufficient command of the Norwegian language, and injuries to the extremities that made testing difficult. A total of 128 patients were eligible. Thirty-two patients were excluded from the study according to the exclusion criteria, and the main reason for exclusion was extremity injuries (22 patients). In addition, 4 patients did not want to participate. The remaining 92 patients were included in the study. They were 63 men (69%) men and 29 women (31%) with a mean age of 37.1 years (SD=13.8) and a mean GCS score of 14.7 (SD=0.7). Fifty-one participants were retested at 6 months. They were 30 men (58.8%) and 21 women (41.2%) with a mean age of 41.4 years (SD=13.2) years and a mean GCS score of 14.8 (SD=0.4).

The participants enrolled in this study were tested for balance problems at 3 months postinjury. They did not receive any physical therapy for their balance problems prior to the testing. Mean symptom severity reported on the Rivermead Post Concussion Symptoms Questionnaire (RPQ) was 16.52 (SD=13.8). Sixty-one participants reported loss of consciousness, 15 did not, and loss of consciousness was unknown for 16 participants. Posttraumatic amnesia (PTA) was reported by 71 participants, 17 participants did not report PTA, and PTA could not be determined in 4 participants. Intracranial injuries and fractures of the skull were identified by computed tomography (CT) scan in 41 participants, no injuries were found in 48 participants, and a CT scan was not performed in 3 participants. The mechanism of injury in the sample was: traffic accidents (n=24), violence (n=24), fall (n=35), and "other" (n=9).

A subgroup of 25 participants was recruited for the intertester and intratester reliability testing of the HiMAT. They were 15 men (60%) and 10 women (40%) with a mean age of 36.8 years (SD=13.7) and a mean GCS score of 14.5 (SD=0.7). The dropouts from 3 to 6 months (n=41) were significantly younger (P=.001), and the group consisted of significantly more men (P=.05) than those who attended for 6 months. There were, however, no significant differences in the GCS scores.

Measures

Demographic and personal factors that were recorded were age, sex, and physical activity. Physical activity postinjury was recorded as sessions per week that made the person sweat and short of breath and lasted for 20 minutes or more. For the purpose of analysis, age and physical activity were categorized into 4 subgroups. Age was categorized into: subgroup 1=16−29 years (n=34), subgroup 2=30−39 years (n=17), subgroup 3=40−49 years (n=19), and subgroup 4=50+ years (n=22). Physical activity was categorized in subgroups based on quartiles: subgroup 1=no physical activity (n=30), subgroup 2=1 to 2 sessions of physical activity per week (n=26), subgroup 3=3 sessions of physical activity per week (n=15), and subgroup 4=4 or more sessions of physical activity per week (n=21).

The HiMAT is a unidimensional performance-based measure of mobility.[8] It consists of 13 walking, running, skipping, hopping, and stair items that are measured with either a stopwatch or a tape measure.[8,16] Raw scores measured in times and distances are noted and converted to a score on a 5-point scale from 0 to 4, except the 2 dependent stair items that are rated on a 6-point scale from 0 to 5.[8–11] For all items, the categories of the converted scores were determined by calculating performance quartiles for successful attempts based on the findings of a study by Williams et al[8] of patients with severe TBI. A score of 0 corresponds to inability to perform the item, and scores of 1 to 4/5 represent increasing levels of ability. The sum score range is 0 (worst) to 54 (best). A user or instruction manual for testers describing the test in detail has been developed.[16] Norms have been established for young men and women who are healthy.[12] The HiMAT has been translated into Norwegian according to recommended procedures.[17]

Self-reported balance problems were recorded using the RPQ.[18] The RPQ is designed to measure severity of post-concussion symptoms following MTBI.[18,19] It is a 16-item standardized and validated questionnaire[18] with a 5-point ordinal scale from 0 (no problem) to 4 (severe problem). The RPQ scores are the sum of symptom scores, excluding the ratings of 1 because this rating signifies a level that is the same as preinjury. In the last section of the RPQ, it is possible to ask the patient whether he or she is experiencing any other difficulties. We added a question about balance applying the same response scale.[18,19] The question was: "Do you now suffer from balance problems?" The balance question was analyzed separately. The response was dichotomized to no balance problems (0−1) and balance problems (2−4) for the analyses. This was the method used for identifying individuals with balance problems in this study. In the lack of a proper gold standard, the balance item of the extended RPQ also was used as a criterion in the validity analyses and as an anchor in the responsiveness analyses in the current study.

Procedure

For the validity and responsiveness testing of the HiMAT, the same physical therapist (I.K.) tested all participants on both occasions. For the assessment of intertester reliability, 3 physical therapists with several years of experience working with patients with TBI participated in the testing. All 3 physical therapists received instruction in use of the HiMAT prior to testing. The intertester reliability testing was performed concurrently and independently by 2 physical therapists, where one therapist was instructing the patient and both were timing the test. The distance in the HiMAT bound item was measured by one physical therapist in accordance with the reliability study by Williams et al.[11] For the intratester reliability testing, the participants were allocated to 2 groups. Group 1 was tested by 2 physical therapists in the morning and retested in the afternoon on the same day by the instructing physical therapist. The procedures were reversed for group 2. The testers were blinded to the scores of the other testers and to their own previous test results. The participants filled in the RPQ prior to the HiMAT testing at 3 and 6 months.

Data Analysis

Descriptive statistics were used for the analysis of demographic data and test data from the HiMAT and the RPQ. Parametric and nonparametric statistical methods were used on normally and non–normally distributed data, respectively. Sensitivity analyses were performed due to outliers. The outliers were kept in the analyses because of similar statistical results. A ceiling effect was considered present if more than 15% of the respondents had the highest possible sum score on the HiMAT.[20]

Criterion-related validity was assessed by Spearman rho between the HiMAT sum score and the RPQ balance score at 3 and 6 months. Discriminant ability of the HiMAT was assessed with receiver operating characteristic (ROC) curve analyses at 3 and 6 months. Differences in the HiMAT score between participants reporting balance problems and those reporting no balance problems were analyzed with the Mann-Whitney *U* test.

For each of the HiMAT items, interrater reliability of the raw scores and the converted scores was assessed with intraclass correlation coefficients (ICCs) (model: 2-way mixed, type: consistency). Interrater and intrarater reliability of the HiMAT sum score also were assessed with ICCs. According to Rosner,[21] an ICC less than .40 indicates poor reproducibility, ICC values from .40 to .75 indicate fair to good reproducibility, and an ICC value greater than .75 shows excellent reproducibility. Mean differences between the initial and retest scores in the intrarater test were calculated with paired *t* test on the group's sum score.

Standard error of measurement (SEM) was calculated with the formula:

$$\text{SEM} = \text{S} \times \sqrt{1 - \text{RC}},$$

where SD is the mean of the standard deviation for the first and second tests and RC is the ICC reliability coefficient. The minimal detectable change (MDC) for the HiMAT score was calculated with the formula:

$$\text{MDC} = \text{m} \pm 1.96 \times \sqrt{2} \times \text{SEM},$$

where m is the mean difference between the initial and retest scores in the intrarater test.[11,22]

Responsiveness of the HiMAT was assessed by calculation of the proportions of participants who reported improvement in balance on the RPQ and had a change of at least the MDC score on the HiMAT. Responsiveness also was analyzed by ROC curve analyses. Change scores of the RPQ balance question were regrouped into 3 categories: "improved," "unchanged," and "worsened." *Unchanged* was defined as no change, and *improved* and *worsened* were defined as a change of one or more score levels except from 0 to 1 and 1 to 0, which represent no real change. Only 2 participants worsened and were excluded from the responsiveness/ROC curve analyses. For the HiMAT sum score, only scores equal to or greater than the MDC were defined as change. Change scores on the RPQ were explored by ROC curve analysis using this dichotomized scale of improved and unchanged participants as the state variable and the change in HiMAT sum score equal to or greater than the MDC as the test variable. The area under the curve (AUC) was interpreted according to Hosmer and Lemeshow[23]: $0.70 \leq \text{AUC} < 0.80$ is considered acceptable discrimination, and $0.80 \leq \text{AUC} < 0.90$ is considered excellent discrimination.

The associations between the HiMAT sum score and age, sex, and physical activity at 3 months were analyzed with multiple linear regression analysis, enter method. Age, sex, and physical activity were included as independent variables, and the HiMAT sum score was the dependent variable. The assumptions underlying linear regression analyses were assessed and found to be adequately met.

Results are presented as mean with standard deviation or 95% confidence interval (95% CI) or as median with interquartile range (IQR). A 2-tailed significance level of .05 was applied. The IBM Statistical Package for the Social Sciences statistics program, version 18.3, (IBM Corporation, Armonk, New York) was used for the statistical analyses.

Results

The mean HiMAT sum score was 46.2 (95% CI=44.4 to 48.1) at 3 months (n=92) and 47.7 (95% CI=45.8 to 49.5) at 6 months (n=51). Some ceiling effect was present, as 21 participants (22.8%) had a maximum score of 54 points at 3 months and 9 participants (17.6%) had the maximum score of 54 points at 6 months. All except one of the participants were men. Seventeen participants (81%) in the youngest age groups (up through 39 years) had the highest possible HiMAT score. The group that was physically active more than 3 times a week had the largest ceiling effect, where 52% of the participants achieved the highest possible score. Ceiling effects for each HiMAT item are shown in Table 1. The stair items had the most substantial ceiling effect, with more than 90% of the participants obtaining the maximum score. Running

Table 1.
Ceiling Effect for the Respective High-Level Mobility Assessment Tool (HiMAT) Items Tested at 3 Months and 6 Months Postinjury

HiMAT Item	n (%) With Maximum Score at 3 Months (n=92)	n (%) With Maximum Score at 6 Months (n=51)
Walk	54 (58.7)	35 (68.6)
Walk backward	62 (67.4)	37 (72.5)
Walk on toes	55 (59.8)	38 (74.5)
Walk over obstacle	50 (54.3)	35 (68.6)
Run	34 (37.0)	13 (25.5)
Skip	34 (37.0)	21 (41.2)
Hop forward (more-affected leg)	47 (51.1)	24 (47.1)
Bound (more-affected leg)	40 (43.5)	22 (43.1)
Bound (less-affected leg)	51 (55.4)	26 (51.0)
Up stairs dependent	90 (97.8)	51 (100)
Up stairs independent	86 (93.5)	50 (98.0)
Down stairs dependent	90 (97.8)	51 (100)
Down stairs independent	84 (91.3)	48 (94.1)

and skipping had the least ceiling effect, with 37% of the participants obtaining the maximum score (Tab. 1).

Balance problems were reported by 28 participants (30.4%) at 3 months and by 14 participants (27.5%) at 6 months. The HiMAT sum score was significantly and negatively associated with self-reported balance measured with the RPQ (at 3 months: rho=−.46, $P<.001$; at 6 months: rho=−.63, $P<.001$). The differences in HiMAT scores for participants with and without balance problems were significant (P=.001), with a difference of 9.5 and 12.0 points at 3 and 6 months, respectively (Fig. 1).

The ROC analyses demonstrated that the HiMAT had good ability to discriminate between participants with and without balance problems at 3 months (AUC=0.78, P=.001) and at 6 months (AUC=0.90, P=.001). The cutoff point on the HiMAT scale that showed the best balance between sensitivity and specificity was less than 47 points at 3 months and less than 48 points at 6 months (Fig. 2).

Interrater reliability for the 2 examiners was excellent for the raw score for each item, showing considerable agreement in the scoring of the different items. Some raw scores were designated to different categories in the converted score, explaining the differences in ICC for the raw scores and converted scores (Tab. 2). However, the differences were minimal, and the converted scores were used to calculate the HiMAT sum score. Interrater reliability for HiMAT sum score also was excellent (ICC=.99, 95% CI=.98 to 1.00).

The intrarater reliability of the HiMAT sum score was excellent (ICC=.95, 95% CI=.89 to .98), showing consistent test results. When comparing the mean test-retest differences, a mean improvement of 0.8 point was found (range=−3 to 7, P=.07).

Minimal detectable change at the 95% confidence level (MDC_{95}) for HiMAT was calculated to be ±3.25. Considering that the mean improvement was 0.8 and the HiMAT score was calculated in whole numbers, a deterioration of 3 points ($-3.25+0.8=-2.45\approx-3$) or an improvement of 4 points ($3.25+0.8=4.05\approx4$) was needed to be 95% sure that a true change had occurred.

The HiMAT's ability to discriminate over time between improved and unchanged participants (responsiveness) was significant according to the ROC curve analyses (AUC=0.86, P=.003, n=49) (Fig. 3). The majority of participants (n=42) reported no change in self-reported balance from 3 to 6 months, 7 reported improvement, and 2 reported deterioration in self-reported balance on the RPQ. The proportion of participants who had improved by at least the MDC on the HiMAT was 85.7% for those with self-reported improved balance on the RPQ compared with 21.4% for those with unchanged self-reported balance.

The multiple linear regression analysis showed that age, sex, and physical activity were significantly and independently associated with the HiMAT score and that these variables explained 40% of the variance in the HiMAT score. Age was a strong predictor of mobility and balance as measured by the HiMAT. Participants aged 40 years and older had HiMAT scores that were a mean of 8.2 points (SD=−12.5 to −4.0) lower than those of the youngest age group when adjusted for sex and physical activity. Men performed a mean of 4.4 points (SD=1.0 to 7.7) better than women when HiMAT scores were adjusted for age and physical activity. Being physically active was a significant predictor compared with being inactive. Physical activity once or twice a week improved the HIMAT performance by a mean of 5 points (SD=1.2 to 8.9), and the most physically active participants scored a mean of 8.2 points (SD=4.0 to 12.4) higher compared with the inactive group when controlling for age and sex (Tab. 3).

Discussion

In this longitudinal study of patients with MTBI, validity, reliability, and responsiveness of the HiMAT were examined. Satisfactory measurement properties were found, and our study complements previous examinations of measurement properties of the HiMAT from Australia.[10,11] However, previous studies have not addressed measurement properties of the HiMAT for the MTBI population.

The sample in our study was representative of other MTBI populations with respect to sex and age distribution.[24] Our sample, however, may represent patients with more severe MTBI, as they were recruited from the neurosurgical ward at Oslo University Hospital. A relatively large proportion of patients were excluded from the study due to fractures or multitrauma that affected their ability to do the test. There is a high incidence of multitrauma in patients with TBI,[5,25,26] which limits the applicability of the HiMAT early after the injury.

Validity

In our study, the significant correlations between reported balance problems on the RPQ and the HiMAT indicate that HiMAT performance reflects balance and mobility problems in patients with MTBI. However, according to quality criteria proposed by Terwee et al,[20] the correlation should be at least .70 to represent a good gold standard. In the present study, only the correlation at 6 months (rho=.63) approached this criterion. Furthermore, the ROC curve analyses showed that the HiMAT discriminated well between

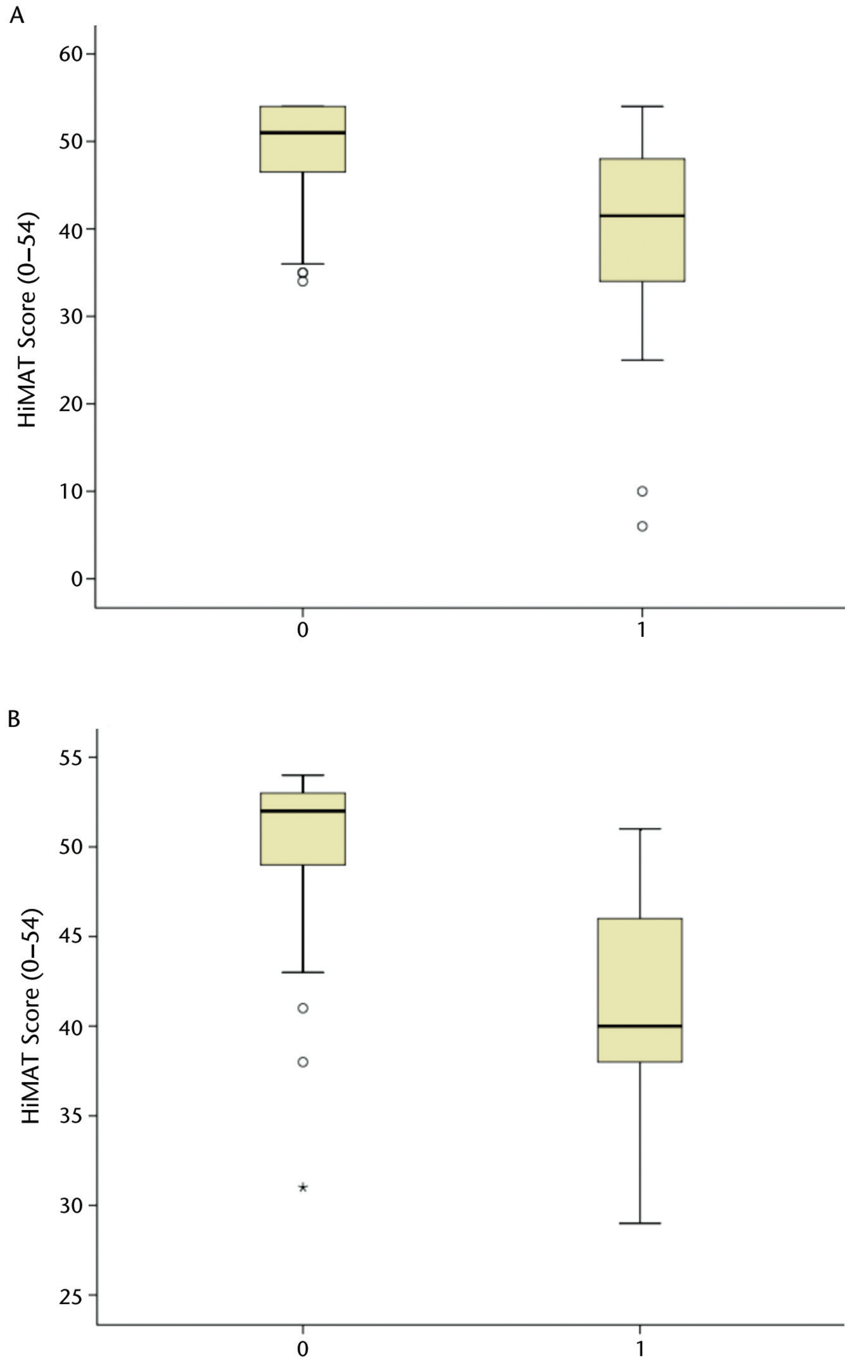

Figure 1.
Box plots demonstrating High-Level Mobility Assessment Tool (HiMAT) scores for participants reporting no balance problems (0) and balance problems (1) on the Rivermead Post Concussion Symptoms Questionnaire at (A) 3 months postinjury and (B) 6 months postinjury. The middle line represents the median, the box represents the interquartile ration (IQR), and the whiskers represent the lowest and highest values except for outliers. Individual circles represent outliers. In Figure 1A, for no balance problems, median HiMAT score=51, IQR=46.2−54; for balance problems, median HiMAT score=41.5, IQR=33.5−48.5. In Figure 1B, for no balance problems, median HiMAT score=52, IQR=48−54; for balance problems, median HiMAT score=40, IQR=38−46.3.

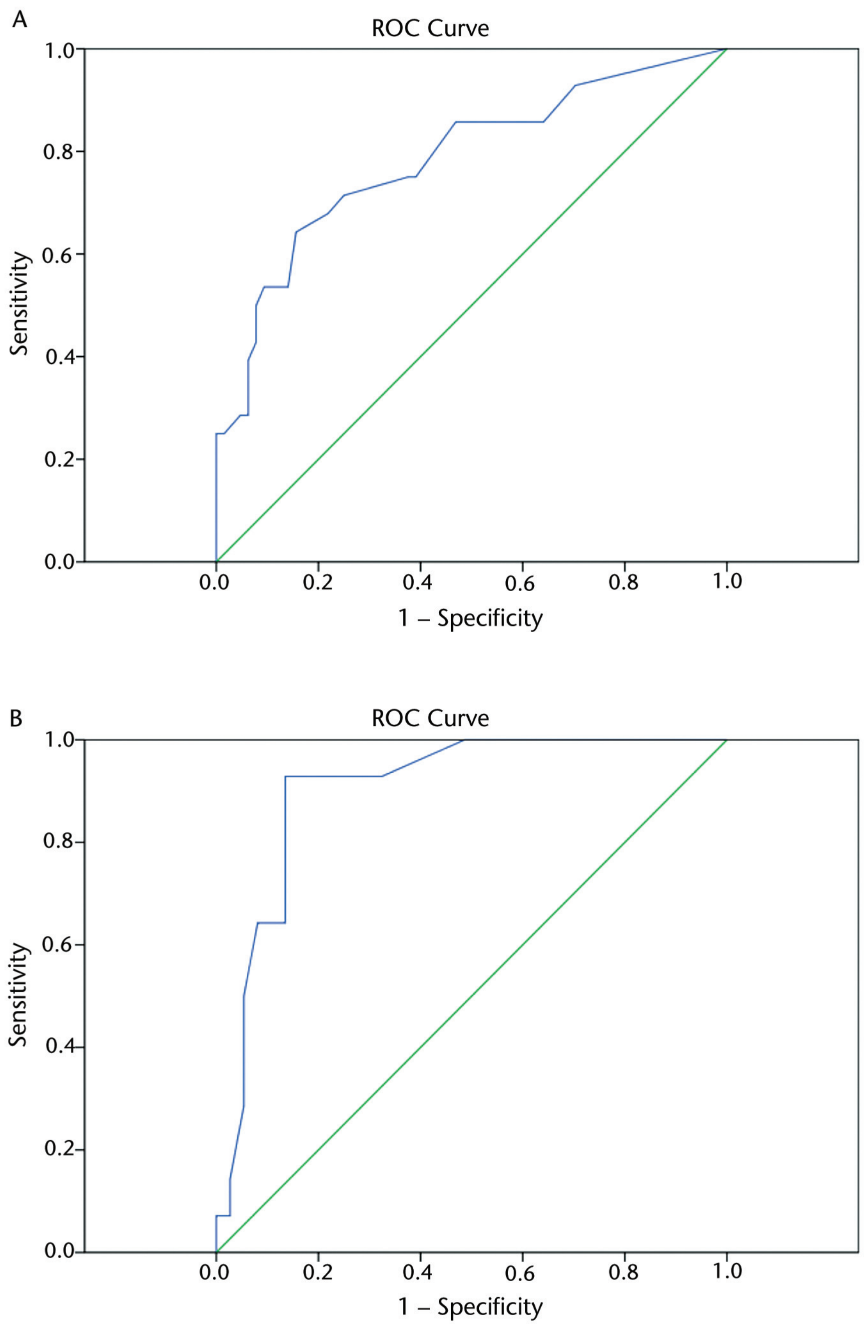

Figure 2.
Receiver operating characteristic (ROC) curves demonstrating ability of the High-Level Mobility Assessment Tool (HiMAT) to discriminate between participants who reported balance problems and those who reported no balance problems on the Rivermead Post Concussion Symptoms Questionnaire at (A) 3 months postinjury (n=92) and (B) 6 months postinjury (n=51). True positive rate (sensitivity) is plotted as a function of the false positive rate (100 − specificity) for different cutoff points. Each point on the ROC curve represents a sensitivity-specificity pair corresponding to a particular decision threshold. In Figure 2A, area under the curve (AUC)=0.78, *P*=.001, n=92 (3 months). Participants with balance problems: n=28. Cutoff <47 points on the HiMAT shows the best balance between sensitivity (70%) and specificity (75%). In Figure 2B, AUC=0.90, *P*=.001, n=51. Participants with balance problems: n=14. Cutoff <48 points on the HiMAT shows the best balance between sensitivity (92%) and specificity (86%).

patients with and without self-reported balance problems, indicating that it is a valid measure of balance and mobility problems in the MTBI population.

In the absence of reliable and valid measures for balance and mobility problems specifically designed for the MTBI population, we chose to use self-report by the RPQ as a proxy criterion standard in order to study the HiMAT's ability to measure balance problems. Other frequently used balance and mobility measures such as the Dynamic Gait Index[7,13] and the Rivermead Mobility Index[14] have demonstrated substantial ceiling effects in more severely injured TBI populations; thus, these instruments were not considered feasible in our study on patients with MTBI.[10,27] It is important to be aware of the weaknesses of self-reports because they may be affected by cognitive problems and self-evaluative accuracy.[28] However, self-report measures are considered to reflect similar assessments of functional limitation as performance measures as long as the construct measured by the 2 methods are the same.[29] Furthermore, gait speed is considered a measure of functional balance and disability,[30] and most HiMAT items measure the speed of gait, running, and jumping activities.

Ceiling Effect

A relatively high ceiling effect of the HiMAT was found in our study. The fact that the majority of the study sample reported no balance problems on the RPQ may be one explanation for this finding. In accordance with Williams et al,[12] the ceiling effect was largest for men. In addition, the current study did find a higher ceiling effect among the youngest age groups and the most physically active participants.

Among the HiMAT items, the stair walking items, in particular, had a substantial ceiling effect, whereas the most challenging items were skipping, running, and hopping. These findings are in accordance with the results of an earlier study.[8] In a revised version of the HiMAT, Williams et al[31] removed the stair items. This revised version should be considered for the MTBI population in future studies. A ceiling effect has the potential to limit the HiMAT as an outcome measure in a general population of patients with MTBI. Such a ceiling effect possibly could be avoided by using raw scores, but this approach makes it more difficult to compare HiMAT scores across populations. Another alternative that might need some consideration is to determine new categories by calculating performance quartiles for successful attempts based on an MTBI population. However, more clinically important, there was no ceiling effect on the HiMAT sum score among patients who reported balance problems on the RPQ.

Reliability

In our study, interrater and intrarater reliability were excellent and corresponded well with results from other reliability studies of the HiMAT.[11,12] Because 2 physical therapists tested concurrently and only one did the instruction, the interrater reliability mainly reflects the timing with stopwatches of each item. The test results are in accordance with the results of other studies, showing good interrater reliability of walking speed measured with a stopwatch in TBI populations.[32,33]

There was neither systematic improvement nor deterioration from the first test to the second test of intrarater reliability. This finding suggests that the participants had consistent performances and that there was no significant effect of practice or learning or of fatigue. Because the 2 tests were performed on the same day, there was little chance for a real

Table 2.
Intraclass Correlation Coefficients for Interrater Reliability of High-Level Mobility Assessment Tool (HiMAT) Converted and Raw Scores (n=25)[a]

HiMAT Item	HiMAT Score ICC (95% CI)	Raw Score ICC (95% CI)
Walk	.85 (.70 to .93)	.96 (.92 to .98)
Walk backward	.87 (.72 to .94)	.99 (.98 to 1.00)
Walk on toes	.98 (.95 to .99)	.98 (.96 to .99)
Walk over obstacle	.97 (.92 to .98)	.99 (.98 to 1.00)
Run	.89 (.77 to .95)	.98 (.95 to .99)
Skip	.96 (.91 to .98)	.99 (.99 to 1.00)
Hop forward (more-affected leg)	.98 (.95 to .99)	.99 (.99 to 1.00)
Bound (more-affected leg)	1.00	1.00
Bound (less-affected leg)	1.00	1.00
Up stairs independent	1.00	.94 (.87 to .97)
Down stairs independent	1.00	.98 (.95 to .99)

[a] ICC=intraclass correlation coefficient, 95% CI=95% confidence interval.

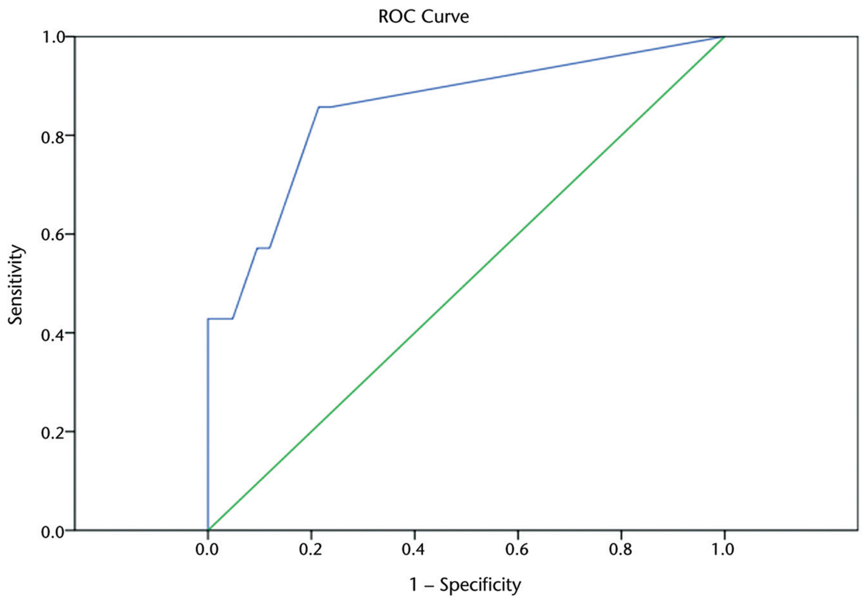

Figure 3.
Ability of the High-Level Mobility Assessment Tool (HiMAT) change scores to discriminate between improved participants (n=7) and unchanged participants (n=42) examined by receiver operating characteristic (ROC) curve analyses. Area under the curve=0.86, $P<.01$ (total n=49). State variable: Rivermead Post Concussion Symptoms Questionnaire balance question, improved=change in 1 or more categories. Test variable: HiMAT sum scores equal to or greater than the minimal detectable change were defined as change (range=−3 to +13).

Table 3.
Multiple Linear Regression Analysis of Associations Between High-Level Mobility Assessment Tool (HiMAT) Sum Score and Age, Sex, and Physical Activity at 3 Months (n=92)[a]

Variable	Unadjusted Results		Adjusted Results	
	B (95% CI)	*P*	B (95% CI)	*P*
Gender: Women/men	6.4 (2.6 to 10.1)	.001	4.4 (1.0 to 7.7)	.001
Age group 2 vs age group 1	−5.0 (−9.7 to −0.2)	.04	−4.3 (−8.6 to 0.07)	.05
Age group 3 vs age group 1	−10.6 (−15.1 to −6.0)	<.001	−8.2 (−12.5 to −4.0)	<.001
Age group 4 vs age group 1	−7.4 (−11.7 to −3.0)	.001	−5.1 (−0.1 to 1.0)	.01
Physical activity 1−2 times vs no physical activity per week	6.3 (2.0 to 10.1)	<.01	5.0 (1.2 to 8.9)	.01
Physical activity 3 times vs no physical activity per week	6.1 (1.0 to 11.2)	.02	6.2 (1.6 to 10.7)	.01
Physical activity 4 and more times vs no physical activity per week	10.7 (6.0 to 15.3)	<.001	8.2 (4.0 to 12.4)	<.001

[a] Age groups: 1=16−29 years, 2=29−39 years, 3=40−49 years, 4=50+ years. Physical activity: 1=0 sessions per week, 2=1−2 sessions per week, 3=3−4 sessions per week, 4=>4 sessions per week. Adjusted results: controlled for age, sex, and physical activity. Unadjusted results: not controlled for age, sex, and physical activity. B=unstandardized coefficient, 95% CI=95% confidence interval.

change or natural recovery. We conducted a practice trial, but cannot rule out an effect of learning with only a few hours between the tests. Also, with the relatively short timespan between the tests, we cannot rule out fatigue as a possible effect for some participants. The range of HiMAT scores was larger in this study compared with the study by Williams et al,[11] suggesting a larger variability and possibly a larger influence of confounding factors in the MTBI population. Cognitive dysfunction, behavioral problems, and motivation are factors that might fluctuate between tests and thereby affect the results.[11]

The nonsignificant change between test and retest in our study led to a slightly different MDC compared with that reported by Williams et al.[11] However, the difference was only 1 point on the HiMAT scale, and we consider this difference not to be of clinical importance. The results of the interrater and intrarater reliability testing in the current study, however, should be interpreted with caution due to the sample size of n=25, which is low according to Terwee et al,[20] who proposed a sample size of ≥50.

Responsiveness

The responsiveness of the HiMAT in our study was good according to recommended criteria.[20] This finding is in accordance with the Australian study on responsiveness of the HiMAT,[10] supporting the notion that this is a responsive instrument, also for the MTBI population. *Responsiveness* is defined as the ability of an instrument to detect a clinically important change over time, even if the change is small.[20,34] It is important for a responsive instrument to measure changes only if they really have happened.[20] In our study, most participants reported the same balance status at retest, suggesting that they had no real change in balance, which was confirmed by the responsiveness analyses. Despite weaknesses of the external anchor used in the current study, the AUC was above 0.70, which is considered adequate.[20]

As expected, age, sex, and physical activity were significantly related to the HiMAT score. In our study, age was a strong predictor of mobility and balance measured by the HiMAT. The regression analysis showed that patients 40 years of age and older had HiMAT scores that were about 8 points lower than those of the youngest age group when adjusted for sex and physical activity. In addition, men performed 4 points better than women when scores were adjusted for age and physical activity. Being physically active was a significant predictor of HiMAT performance compared with being inactive. Physical activity once or twice a week was sufficient to improve HiMAT performance significantly, and the most physically active participants scored 8 points higher compared with the inactive group when controlling for age and sex. Our results suggest that norms also should be established for physical active and inactive groups. Establishing age- and sex-specific norms, including norms for physical activity, will increase the interpretability and feasibility of the HiMAT and should be a focus of future research.

Limitations

Several limitations and challenges of the current study have already been discussed in relation to quality criteria proposed by Terwee el al.[20] As for many other validity studies, the present study lacked a gold standard, and we recognize the weaknesses of using self-reported balance as measured with the RPQ as a criterion and anchor in the analyses. Furthermore, the relatively high ceiling effect has the potential to limit both the reliability and responsiveness analyses, as many participants had no possibility of improvement or change on the HiMAT. Furthermore, the relatively small sample size was a limitation.

Conclusion

In our study, the HiMAT demonstrated satisfactory measurement properties for patients with MTBI. This finding is in agreement with previous results on the original version of the HiMAT. Our findings suggest that the HiMAT can be used as an outcome measure of balance and mobility problems in patients with MTBI. However, the results should be interpreted with some caution due to the methodological challenges, small sample size, and lack of a gold standard in our study.

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The Norwegian Regional Committee for Medical Research Ethics approved the study (#171.08).

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